

## **UNITED STATES AIR FORCE RESEARCH LABORATORY**

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### **AN ASSESSMENT OF THE EFFECTS OF FOUR ACOUSTIC ENERGY DEVICES ON ANIMAL BEHAVIOR**

**Clifford Sherry  
Michael Cook  
Carroll Brown**

**VERIDIAN ENGINEERING  
9601 McAllister Freeway, Suite 1165  
San Antonio, Texas 78216**

**James Jauchem  
James Merritt  
Michael Murphy**

**AIR FORCE RESEARCH LABORATORY  
HUMAN EFFECTIVENESS DIRECTORATE  
BIODYNAMICS & PROTECTION DIVISION  
2504 Gillingham Drive  
Brooks AFB, Texas 78235-5104**

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JAMES H. MERRITT  
Contract Monitor

  
RICHARD L. MILLER, PhD  
Chief, Directed Energy Bioeffects Division

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# AN ASSESSMENT OF THE EFFECTS OF FOUR ACOUSTIC ENERGY DEVICES ON ANIMAL BEHAVIOR

## INTRODUCTION

### *The Attraction of Acoustic Weapons*

The military services have an interest in non-lethal technology designed to disorient, incapacitate, confuse, or repel individuals or groups, without causing acute or long-term injury. These non-lethal weapons can potentially offer a more effective, appropriate response than can traditional weapons in support of peacekeeping, peace enforcement, and tactical combat operations. These operations cover a broad range of scenarios, from controlling passive crowds, to responding to riots and attacks on U.S. personnel, to deterring or countering terrorist attacks on U.S. territory (Council on Foreign Relations, 2000). To avoid conflicting and false expectations, it is essential that military commanders and policymakers understand the real capabilities and limitations of non-lethal technologies before putting them into the hands of troops.

Certain requirements must be met in order for an acoustic non-lethal weapon to be acceptable for use in the field. First, it must produce obvious measurable effects (e.g., driving a subject away from a goal-oriented task). The effects should occur rapidly (within 3-5 seconds of application), be reversible, and cause no permanent damage to body organs or hearing. The effects should not be due simply to a "startle response" (elicited by the loud noise) that will diminish with repeated applications of the weapon. Ideally, an acoustic non-lethal weapon system should be portable with an effective range adequate to allow the operator to apply it at a safe distance (at least 15 meters).

A number of statements have appeared in the popular press indicating that research on acoustic energy has progressed to such a stage that "acoustic weapons" will soon be a reality on the battlefield. Lewer and Schofield (1997) stated that acoustic weapons were at an advanced stage of production, including those developed by Scientific Applications & Research Associates, Inc. (SARA, Huntington Beach, CA; mentioned later in this report). Tapscott and Atwal (1993) quoted one individual as saying: "Proof of principle has been established; we can make relatively compact acoustic weapons." Regarding effects on soldiers, Aftergood (1994) said: "Acoustic beam weapons would knock them out"; Cook et al. (1995) remarked: "some of the attackers may experience disorientation, pain, or even death." Pasternak (1997) stated that "acoustic or sonic weapons...can vibrate the insides of humans to stun them, nauseate them, or even liquefy their bowels and reduce them to quivering diarrheic messes..." O'Connell and Dillaplain (1994), on the basis of an interview at SARA, suggested that acoustic technology could meet weapons requirements, resulting in a system with tunable effects, ranging from temporary discomfort to lethality. The implication was that such weapons would be used "when they become a part of our arsenal," not if they become a part of the arsenal.

Unfortunately, despite the claims above, the reported bio-effects data dealing with exposures to high-intensity acoustic energy fall into several categories. They are anecdotal; reported only

in meeting abstracts or technical reports; 20-40 years old; or incomplete, providing little or no information about the spectral content of the acoustic energy. Furthermore, arguing the practical limitations of technology, Altmann (1999) has suggested that based upon basic physical principles, the development of a useful weapon using high-intensity acoustic energy is unlikely. Such acoustic waves will propagate from a source in all directions, thus reducing the power delivered to any given area. Alker (1996) noted that a source with the capacity of a nuclear reactor would be required for an acoustic weapon to have a range of tens of meters. Finally, it is very difficult to cause fatal injuries with high-intensity acoustic energy. The minimum acoustic energy necessary to cause a potentially lethal injury in a 70-kg, human-size animal is approximately 30-42 psi. To put that number into some perspective, 5 psi (or about 184 dB) is the threshold for ear drum failure and is about the amount of acoustic energy experienced 350 meters from an explosion of 500,000 pounds of TNT equivalent (Wilhold et al., 1990).

### *The Interaction of Acoustic Energy with Biological Organisms*

In the audible frequency range (20–20,000 Hz), the ear absorbs 90% of the impinging acoustical energy, while the rest of the body reflects more than 98% of the acoustic energy. The reason the body does not absorb sound is that there is a mismatch between the characteristic acoustic impedance of air and the body surface (von Gierke, 1972). Therefore, potential bio-behavioral effects of high-intensity acoustic energy in the sonic and audible frequency ranges can be divided into three categories: (a) aural (hearing) — temporary or permanent threshold shifts; (b) extra-aural effects caused by hearing — activation of the sympathetic nervous system (increase in heart rate, blood pressure, breathing rate, etc.); and (c) non-hearing extra-aural effects — pain, middle or inner ear damage, somatosensory and vestibular disturbances. Because of the impedance mismatch, it is very unlikely that acoustic energy in the audible frequency range will have any direct effect on internal organs. The aural-based effects typically disappear when a temporary or permanent threshold shift occurs. It is important to note that a permanent threshold shift does not imply that the subject experiences silence. Often a permanent threshold shift is accompanied by a persistent ringing sensation.

There are dozens of meeting abstracts, technical reports, and papers in refereed journals dealing with the effects of blast overpressure on tissue equivalents, animal models, and humans. Data collected in blast overpressure experiments indicate that the auditory system, especially the eardrum (e.g., Richmond et al., 1989) and the inner ear (e.g., Roberto et al., 1989), are most susceptible to damage by high-intensity sound. Anatomical structures that contain gas or fluids, such as the respiratory and gastrointestinal systems, are also susceptible (e.g., Stuhmiller, 1990 [modeling]; Wang, 1989 [empirical]).

Nausea and/or vomiting can be caused by several mechanisms, including: (a) a change in the activity of the labyrinth and/or otolith organs (Previc, 1993; von Gierke and Parker, 1994); (b) a change in the activity of the abdominal viscera graviceptors (von Gierke and Parker, 1994); and (c) gastric tachyarrhythmias (Hu et al., 1991; Pezzolla et al., 1989; Xu et al., 1993). It is possible that high-intensity acoustic energy could act through any of these mechanisms.



## Objectives

The Directed Energy Bioeffects Division of the U.S. Air Force Research Laboratory performed a research program for the U.S. Army's Armament Research, Development, and Engineering Center. The primary goal of the project was to determine if narrow-band, high-intensity acoustic energy in the audible frequency range could be used as a non-lethal weapon; that is, could it disrupt the goal-directed behavior of a highly-motivated non-human surrogate without causing a permanent threshold shift in hearing. Three categories of acoustic devices, whose outputs were in the audible frequency range, were tested. The first category was comprised of two continuous-wave acoustic sirens, each designed and delivered by SARA. The first was a compressed-air-driven siren (CADS), designed for use in the confines of an indoor laboratory, while the second was a similar combustion-driven acoustic siren (the Dismounted Battlefield Battle Laboratory, or DBBL), which was designed for outdoor testing. The second category, impulsive acoustic devices, was represented by the Sequential Arc Discharge Acoustic Generator (SADAG), developed by the Army Research Laboratory (ARL). Finally, the third category, complex waveform devices, was represented by a device known as the Gayl Blaster, named after its developer (Gayl, 1998).

## GENERAL METHODS AND PROCEDURES

### Subjects

All animals used in the experiments described below were procured, maintained, and used in accordance with the Animal Welfare Act and the Guide for the Care and Use of Laboratory Animals prepared by the Institute of Laboratory Animal Resources, National Research Council, under protocols that were approved by the USAF Research Laboratory (Armstrong Site) Institutional Animal Care and Use Committee and by the USAF Surgeon General.

Micropigs and minipigs (*Sus scrofa*) were supplied by Charles River Laboratories (Wilmington, MA). They were individually housed in pens (3.0 m long x 1.0 m wide x 2.0 m high) with cement floors. The room temperature was maintained at  $24 \pm 2^\circ \text{C}$  with a 12:12 hour light:dark cycle. Water was always available ad libitum in their stalls. Except during testing, approximately 1.0 to 2.3 kg of Purina Mills Minipig HF Grower (Purina Mills, Inc., St. Louis, MO) was provided to each subject in the morning and afternoon. This diet was occasionally supplemented with fresh fruit. Beginning one day prior to testing, food was withheld from subjects and was not made available again until immediately following testing.

Rhesus monkeys (*Macaca mulatta*) were acquired from the rhesus colony maintained at Brooks Air Force Base, TX. Monkeys were housed individually in standard stainless steel cages; cage sizes were either 118.7 cm high x 88.9 cm wide x 86.4 cm long (for relatively large monkeys) or 77.5 cm high x 61.0 cm wide x 71.1 cm long (for smaller monkeys). Room temperature was maintained at  $24 \pm 2^\circ \text{C}$  with a 12:12 hour light:dark cycle. Subjects were provided approximately 0.2 kg of Purina Mills Monkey Diet both in the morning and the afternoon. This was supplemented approximately twice a week with fresh fruit. Water was available ad libitum.



Goats (*Capra hircus*) were acquired from the colony located at Brooks Air Force Base, TX. For one of the studies to be described (employing the DBBL acoustic device), subjects were housed together in a large outdoor pen located near the test site at Philips Laboratory, Kirtland Air Force Base, NM. In a second study to be described (using the Gayl Blaster) subjects were housed in a large outdoor pen (14.8 m long x 12.3 m wide). In each of the two pens water and hay were available on an ad libitum basis. Except during testing periods, subjects were also provided approximately 1.1 kg of Purina Mills Rumilab Diet both in the morning and the afternoon. Beginning one to two days prior to testing, Rumilab was withheld from subjects and was not made available again until immediately following testing.

### *Apparatus and Data Analysis*

*Panel-Pressing Equipment.* Subjects in some of the experiments to be described were trained using the method of successive approximations to press a panel (Sherry et al., 1994). Correct responses were rewarded with the delivery of a favored food. In the case of pigs this was typically cracked corn; for goats it was typically a combination of cracked corn and whole oats (Allied Feeds, San Antonio, TX). Training continued for each subject until a reliable and stable rate of responding was achieved.

Two panel-press devices were employed, one for goat subjects and a second for swine subjects. Both were constructed by Whitmore Enterprises (San Antonio, TX, Model WE 1001). Each panel-press device consisted of a clear Plexiglas panel (the manipulandum) mounted on a large rectangular plane constructed of opaque Plexiglas. The panel was hinged along its top edge. Nylon screws were attached to the back surface of the panel approximately 1.0 cm from its bottom edge and extended (via small holes) back into the large rectangular plane. Pressing the panel had the effect of pushing the screws; when the panel was fully pressed, one of the screws struck and closed a single-pole, double-throw, short-roller microswitch (Selecta Switch, Tehachapi, CA, Model 11A 125/250/277VAL High Force [0.8 oz]), thereby defining a panel-press response. A small spring situated around one of the screws caused the panel to return to its normally open position following completion of a panel press. When a sufficient number of responses were made by the subject, approximately 20 g of food was deposited into a small food well which was also mounted on the front of the rectangular plane.

The dimensions of the supporting rectangular plane, as well as the size and position of the food well and manipulandum differed somewhat for the two panel-press devices. For the swine device, the supporting rectangular plane measured 61.0 cm long x 47.0 cm high; for the goat apparatus, it measured 133.0 cm long x 58.0 cm high. In the case of the swine panel-press apparatus, the manipulandum (15.0 cm long x 18.0 cm high) was mounted 8.0 cm from the left edge of the supporting plane and 15.0 cm above the bottom of the plane. The food well (17.0 cm long x 13.0 cm high x 5.0 cm deep) was positioned at the bottom of the support plane 5.0 cm from the right edge of the plane. In the case of the goat panel-press apparatus, the manipulandum (16.5 cm long x 16.5 cm high) was mounted 33.0 cm from the left edge of the supporting plane and 23.7 cm from the bottom of the plane. The food well (12.7 cm long x 7.6 cm high x 10.0 cm deep) was positioned below and to the left of the manipulandum: 10.1 cm

from the left edge of the plane and 15.2 cm above the bottom. Figure 1 shows the panel-press apparatus employed for the goats.

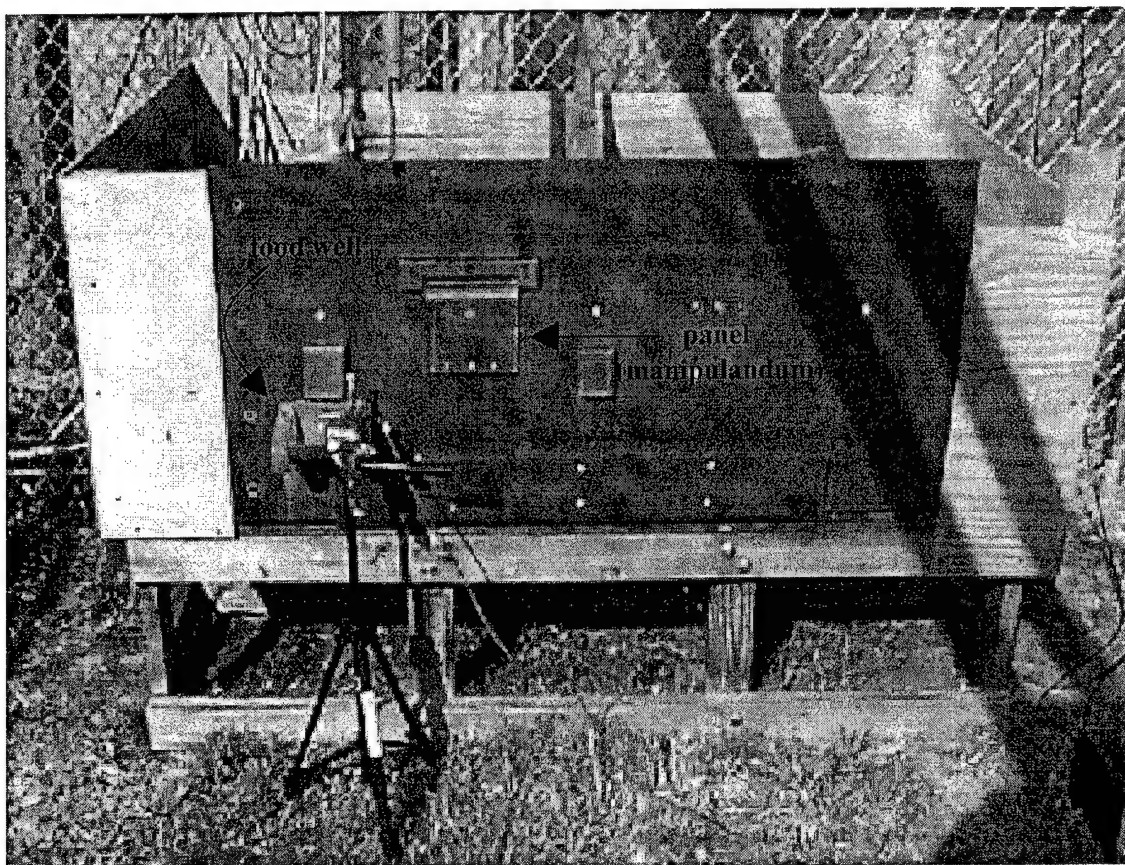


Figure 1. The panel-press apparatus used with the goat subjects configured for an outdoor test. (The food well is partially obscured by a tripod-mounted microphone.)

Delivery of the food and recording of the panel-press responses were further controlled by an Universal Environmental Interface (E91-12), an Environmental Interface Control (S91-12), a Retriggerable One Shot (S52-12), and a Predetermining Counter (S43-30) (all made by Coulbourn Instruments, Allentown, PA). Finally, for some of the studies conducted, panel-press responses were digitally recorded using WINDAQ data acquisition software in conjunction with an analog and digital input/output board (both software and board available from Dataq Instruments, Inc., Akron, OH). The software version number and board model number varied with the different studies.

*Equilibrium Platform.* All rhesus subjects in the present experiments had been previously trained to operate the Primate Equilibrium Platform (PEP). The PEP is a continuous, compensatory tracking task that has been extensively used in assessments of the effects of nerve agents and associated drugs, such as prophylactics, antidotes, and their combinations (Blick et al., 1994; Farrer et al., 1982). Performance on the PEP task measures fine motor control

involved in joystick manipulation and the integrity of the complex sensorimotor system necessary for maintaining equilibrium and orientation in space. The neural system for maintaining orientation/equilibrium is complex and highly integrated, involving several sensory inputs (vestibular, visual, and kinesthetic). Brain centers involved in integrating this sensory information include the cerebellum, sensory cortex, and nuclei of the thalamus, midbrain, and brainstem.

Briefly, a subject performing in the PEP was seated in a restraint chair that rotated on the pitch axis about the subject's center of gravity. A computer (80286 PC with a DAS-8/AO data acquisition and control board [Keithley Instruments, Inc., Taunton, MA]) used a bounded stochastic process to generate random perturbations in pitch. If no monkey were present, there would be large variations in chair position, with a standard deviation of 12-15°. The subject's task was to manipulate a joystick control to compensate for these random perturbations. When the platform position deviated from the horizontal plane by more than 15°, the monkey received a mild electric shock delivered to the tail (100-ms duration, 1-Hz repetition rate, and 5-mA maximum current). A well-trained subject could reduce the variation to 2-4° and receive few, if any, shocks (less than one per hour on average). Figure 2 shows a typical rhesus subject "flying" the PEP.

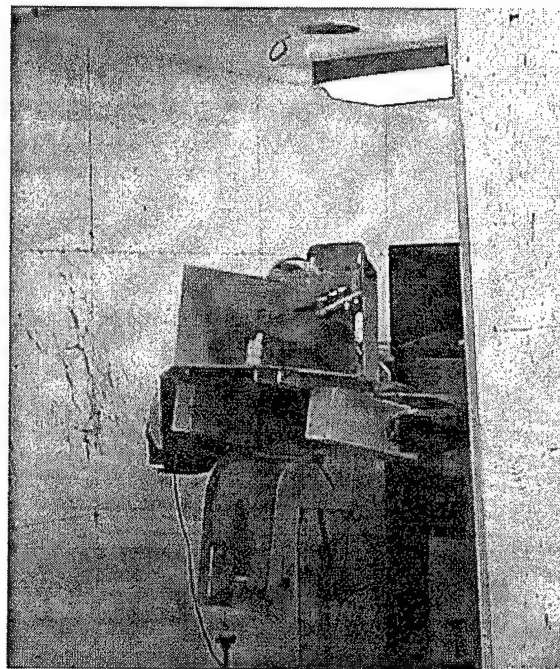


Figure 2. Rhesus monkey operating the Primate Equilibrium Platform.

Sessions in the PEP were 60 min in duration. For purposes of analysis, each 60-min session was subdivided into (a) 24 epochs of 2.5 min each for sessions conducted during the CADS study, and (b) 30 epochs of 2 min each for sessions conducted during the SADAG study. Shock frequency was recorded for each epoch. In addition, during each epoch, chair position (degrees

deviation from the horizontal plane) was measured 10 times per second and these values were used to calculate mean chair position and the standard deviation of chair position for the epoch. Chair standard deviation during an experimental session in the PEP was compared with chair standard deviation during five baseline PEP sessions (which were typically conducted in the period 1-2 weeks prior to the experimental session). More specifically, standard deviation values from the baseline sessions for a given subject were used to determine the range of normal performance for that subject by the method of simultaneous tolerance limits (Lieberman and Miller, 1963). The method consists of fitting a line to the baseline performance values by the method of least squares. Residual variation about the fitted line was used to generate simultaneous tolerance limits ( $p = .99$ ,  $\alpha = .01$ ). A performance decrement occurred when one or more standard deviation values from the experimental session exceeded the upper tolerance limit.

In addition, joystick position, chair position, forcing function, and shocks were digitally acquired using WINDAQ data acquisition software (Version 1.58) with a DI-200 PGH analog and digital input/output board (Dataq Instruments, Inc.), both installed on an 80486 33-MHz PC. These data allowed the detection of moment-to-moment changes in PEP performance that could be missed by the analysis method described above.

*Acoustic Signals.* Accurate and consistent acoustic measurement is essential to an understanding of the bio-behavioral effects of high-intensity acoustical energy. Therefore, a system was utilized that allowed description of the output of our high-intensity sources in terms of frequency, intensity, and duration.

Acoustic intensity measurements were acquired via either one or two Brüel & Kjær (B&K) Model 4136A microphones. The output of each microphone was amplified by a B&K microphone preamplifier (Model 2670 or Model 2633) and a B&K Model 5935 Dual Microphone Supply. The output of the Dual Microphone Supply was digitized, displayed, and analyzed by an in-house program written in LabVIEW (National Instruments, Austin, TX). This LabVIEW application displayed the collected acoustic data in both (a) the time domain and (b) the frequency domain (amplitude [SPL in dB] versus frequency) using the Fast Fourier Transform (FFT) method.

Commercially available FFT analyzers assume that the signal is stationary and therefore have the following characteristics: (a) a minimum number of lines or bins (usually 1024, but typically no more than 4096); (b) analog-to-digital (A/D) conversion at  $2 \times N$ , where  $N$  is the highest harmonic of interest (in Hz); (c) use of frames to accommodate long-duration samples, and averaging of frames in order to minimize standard error. Because the signals analyzed in these studies were rarely stationary, it was not appropriate to use frames to accommodate long samples. That is, averaging the signal would not yield meaningful results. Furthermore, a greater number of lines was needed to distinguish between real effects and artifacts caused by "leakage." The "sensitivity" of an FFT is determined by the ratio of the A/D rate to the number of lines, so it is important to have the largest practical number of lines, and a ratio as close to 1 as practically possible. The in-house LabVIEW application employed an FFT algorithm that had these latter characteristics.



Hardware and software features associated with the LabVIEW program changed over the course of these studies. These changes did not, however, affect the underlying capabilities of the program in such a way that might alter interpretation of the data collected. For the studies examining the CADS, DBBL, and SADAG, the program was compiled with either Version 3.1.1 or 4.0 of LabVIEW's compiler and ran on a 233-MHz Pentium PC with an National Instruments AT-A2150C dynamic signal acquisition board; for the Gayl blaster study the program was compiled with Version 5.1 of the compiler and ran on a 350-MHz Pentium II PC with a National Instruments PCI-4551 dynamic signal acquisition board. Figure 3 shows the program's front panel for configuring a test.

The figure shows a LabVIEW front panel for test configuration. It includes controls for hardware (Audio Card, Channels), sampling rates, test duration, and windowing parameters. A list of test durations is displayed on the right, with 20.164923 highlighted. Control buttons for 'Begin Test' and 'Exit' are located at the bottom right.

Figure 3. Test configuration front panel of the in-house LabVIEW application used for measuring amplitude and frequency of acoustic signals.

The microphones, amplifying circuits, and LabVIEW FFT program were calibrated prior to and immediately following each experimental session using a B&K Sound Level Calibrator (Model 4231), which produced a 1-kHz tone at 94 or 114 dB. Calibrator performance conformed to standards defined by National Institute of Standards and Technology. Figure 4 depicts the output of the FFT program for the calibrator output.

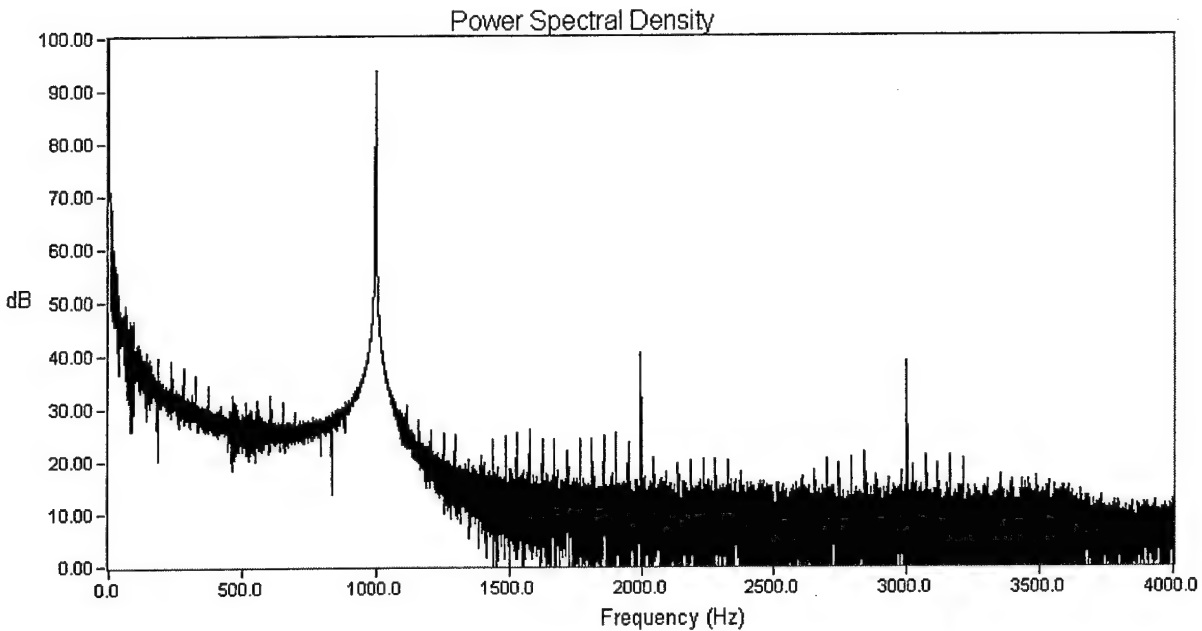


Figure 4. Output of the FFT program when the 94-dB, 1-kHz tone produced by the calibrator is analyzed.

*Hearing Tests.* In order to identify any temporary or permanent auditory threshold shifts, several standard tests were conducted on rhesus subjects prior to and following exposure to the various acoustic devices. The effects of exposure on cochlear and neural mechanisms were determined by performing the following tests: (a) distortion product otoacoustic emissions (DPOAE), which are sensitive to subtle changes in the integrity of outer hair cell in the cochlea (see Brownell, 1990; Laskey et al., 1999); and (b) auditory brainstem evoked responses (ABR), which estimate peripheral auditory sensitivity (see Hall, 1992; Laskey et al., 1999).

DPOAEs measure the status of the outer hair cells of the cochlea. That is, outer hair cells, through micro-mechanical activity, appear to emit acoustic energy following stimulation that is transmitted out through the middle ear into the external auditory canal. Anything that impacts these outer hair cells (e.g., noise, ototoxic medications, illness, etc.) can be detected with by measurement of DPOAEs. (The amplitude of DPOAEs can also be influenced by the status of the middle ear.) Often, hearing thresholds in humans may not change after these insults, yet emissions show some impact. Therefore, they are capable of detecting sub-clinical signs of insult. In addition, using careful measurement techniques, emissions have been shown to have greater than 90% test-retest reliability.

The equipment measuring the DPOAE stimulated the ear with a pair of sounds at frequencies  $f_1$  and  $f_2$ , swept from approximately 500 Hz to 8000 Hz. For these studies,  $f_1$  was presented at 65 dB SPL and  $f_2$  was presented at 55 dB SPL. The resulting DPOAE was then measured at the frequency  $2f_1 - f_2$  (the intermodulation product). This signal was averaged and displayed as amplitude as a function of frequency. The transducers that produced the sounds stimulating the outer hair cells, as well as the microphone used to record the DPOAE, were housed in a probe tip

that was placed in the subject's ear canal. The probe tip was controlled by software running on a 16-MHz Apple Macintosh IIcx. During a given session, each ear was tested twice with the probe being removed and re-inserted between tests. This was done to ensure test-retest reliability. In addition, the output levels of the two transducers were monitored during each test to ensure that amplitude levels were appropriate (55 and 65 dB SPL).

ABR measurements evaluate the neurologic status of the peripheral portions of the auditory nerve pathways by detecting far-field potentials following stimulation of the ear with auditory stimulation. Stimulation was produced via transducers inserted into the ear canal. Two stimuli were used to elicit the ABRs: rectangular clicks and pure tone bursts. The click stimulus had a frequency spectrum that included most of the frequencies important for communication purposes, although, as the click intensity decreased, the stimulus spectrum narrowed and generally included the 2-4 kHz region. Click stimuli were presented at a rate of 61.1 clicks per second. Tone burst stimuli provided some degree of frequency specificity; in the present studies center frequencies of 500 Hz and 4 kHz were specified. Tones were presented at the rate of 21.1 bursts per second.

Electrodes were placed on each earlobe, the vertex of the skull, and the bridge of the nose (for ground). Electrical activity that was time locked to each stimulus was collected, averaged, and displayed graphically as a series of waveforms. The amplitude and latencies of the waves, numbered I-V by convention, were determined. Peripheral auditory sensitivity (or "threshold") was estimated by systematically reducing the intensity of the stimuli. Typically, as the stimulus intensity decreases, the latency of the waves increases and the amplitude decreases. Threshold was set at the last intensity level at which a replicable waveform (response) could be detected. Two tests per intensity level were conducted in order to confirm the presence or absence of a waveform. Timing and delivery of tone and click stimuli, and the recording of resulting ABRs, was accomplished via software from Bio-logic Systems Corporation (Mundelein, IL) running on an 80286 PC.

Subjects were anesthetized during each of the two components of the battery. Anesthetic (propofol) was administered at the rate of approximately 150-200  $\mu\text{g/kg/min}$  over the course of testing. Veterinary personnel were present during the entire procedure and monitored vital signs every 15-30 minutes. The battery typically took 2-3 hr to administer.

## COMPRESSED-AIR-DRIVEN SIRENS

### *Subjects*

Subjects were 5 adult male rhesus monkeys (*Macaca mulatta*) ranging in weight from approximately 7 to 11 kg. Subjects ranged in age from approximately 6 to 7 years at the time of testing. All subjects were housed and maintained as described in the *General Methods and Procedures* section. All subjects had been performing the PEP task on a regular basis for a minimum of 4 years.

## Apparatus

*Acoustic Sources.* SARA designed and built two compressed-air-driven sirens (CADS) designed to allow independent control over frequency and intensity over two different frequency ranges. For one of the two sirens, hereafter referred to as the low-frequency CADS, this range

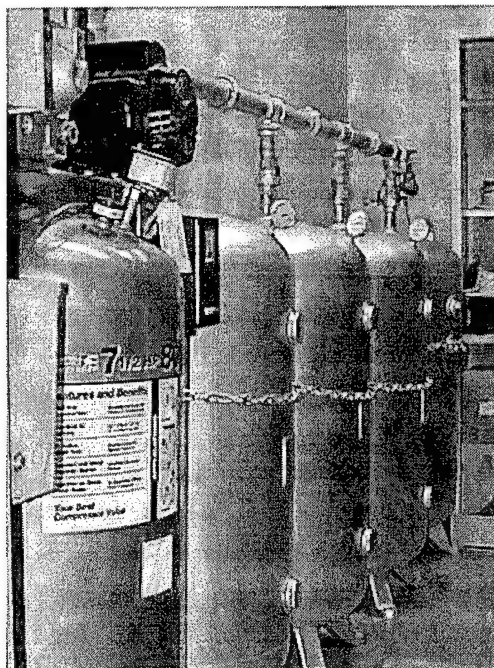


Figure 5. Compressor and storage tanks used with compressed-air-driven sirens.

was approximately 750 to 2500 Hz; for the second siren, hereafter referred to as the high-frequency CADS, the range was approximately 1500 to 10,000 Hz. The compressed air to drive the sirens was provided by a cast iron, 7½-horse-power, 80-gallon, two-stage compressor (Model CI071080VMSA, Campbell Hausfeld, Harrison, OH). The compressor charged a ganged series of four additional 80-gallon storage tanks connected to each other with 5.1-cm-diameter pipe. Both compressor and tanks were housed in a separate room to minimize noise (see Figure 5). A 4.4-cm-diameter steel pipe carried the compressed air to the sirens. Other hardware components employed in controlling the output of the sirens included a motor control unit (used, in part, for specifying the siren frequency), an isolation transformer, and an enabling button. These are shown in Figure 6.

Figure 7 shows the rear side of the low-frequency siren. Pressurized air from the tanks entered the system via a coupling (not seen in the figure) beneath the siren support plate. Flex hoses fed this supply to two sets of air flow valves and pressure regulators, one set on the right



side of the siren head, the other on the left side. A solenoid valve supplied the pressure (a

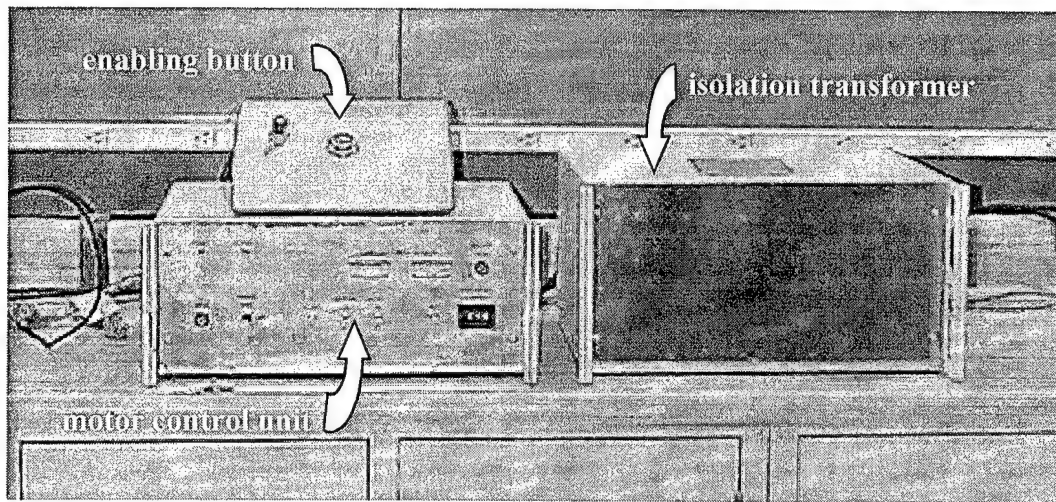


Figure 6. Motor control unit, isolation transformer, and enabling button used with compressed-air-driven sirens.

regulated supply of nitrogen, 125 psi) to open each of the air flow valves. The solenoid valve, in turn, was opened by the enabling button. The pressurized air supply fed into the siren chamber once the air valves were opened, and forced air through a rotor and a series of holes in a stator.

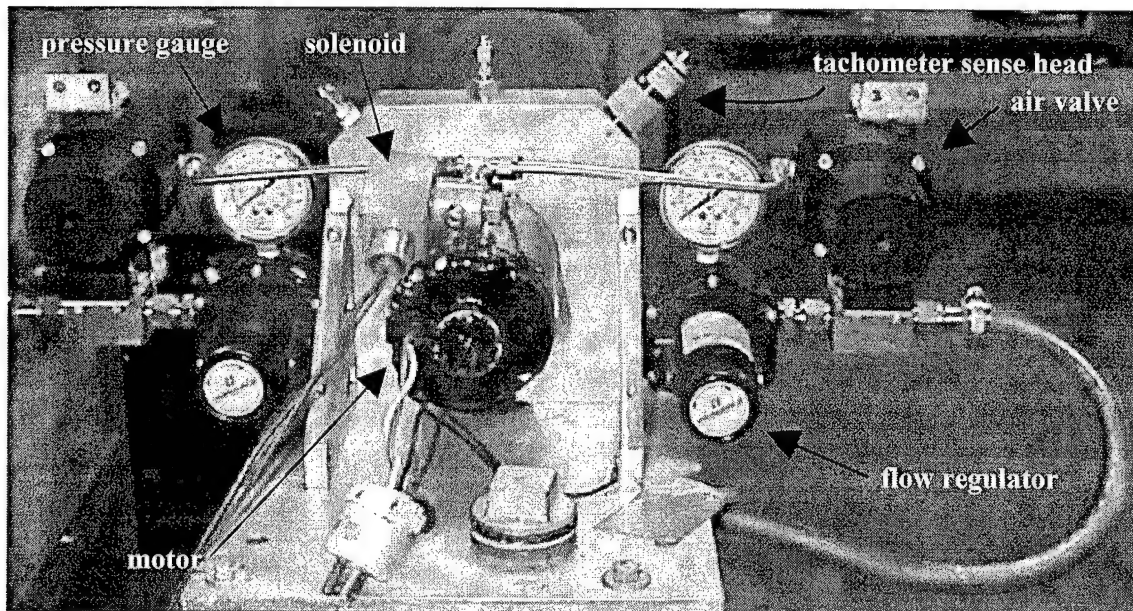


Figure 7. Rear view of low-frequency compressed-air-driven siren.

(Figure 8 shows these holes on the front side of the low-frequency siren.) Rotor speed was monitored via a tachometer sense head (see Figure 7); the signal from this sense head was fed back into the motor control unit. A port at the very top of the siren allowed introduction of a pressure transducer to measure siren chamber pressure, but this design feature was not used during the present tests.

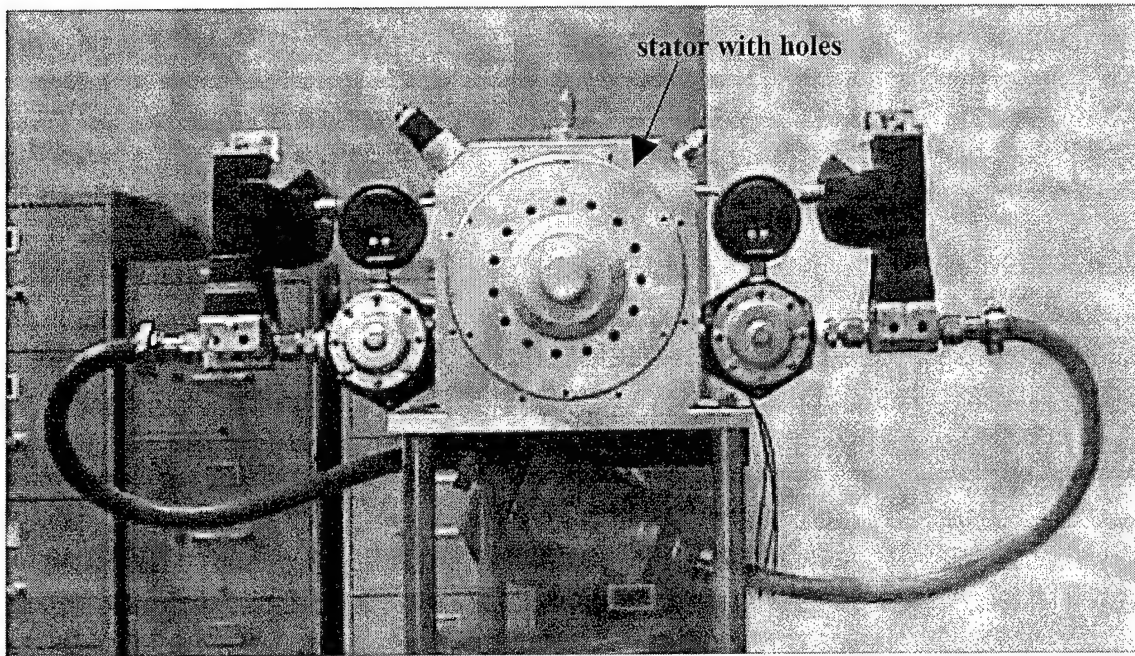


Figure 8. Front view of low-frequency compressed-air-driven siren.

The acoustic power produced by both of the compressed-air-driven sirens was theorized to be a nonlinear function of the volumetric flow of the compressed air and the size and number of holes in the stator and rotor. The frequency of the sound generated depended on the number of holes in the stator/rotor and the speed with which the rotor was spun. Further, one of the design goals of the sirens was the production of an acoustic signal in which approximately 95% of the acoustic power was at the fundamental frequency.

Early tests of the two sirens indicated the presence of significant acoustic side lobes. In other words, intensities were somewhat lower (approximately 5-10 dB) directly along the bore-sight than at the side lobes (maximal intensities were located approximately 25 to 40 degrees off center). A "beam director," designed to suppress these side-lobes and increase power on the bore-sight, was designed by Dr Don Decker of the Naval Air Warfare Center Weapons Division (China Lake, CA). This beam director could be attached to either the low- or high-frequency CADS. Figure 9 shows the beam director attached to the low-frequency siren.

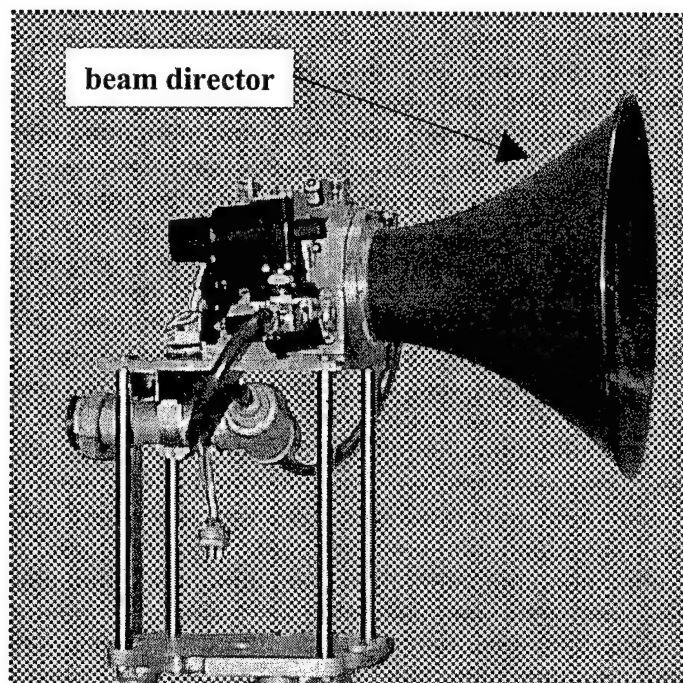


Figure 9. Beam director attached to low-frequency compressed-air-driven siren.

*Equilibrium Platform.* All rhesus subjects were tested in the PEP. The task requirements for the PEP are described in the *General Methods and Procedures* section. For some test sessions, the PEP was fitted with a "baffle" shown in Figure 10. Each of the two rectangular faces of the baffle measured 38.0 cm high x 32.5 cm wide. Testing of subjects without the baffle indicated a substantial performance decrement because the air flow from the siren "caught" the undersurface of the shelf housing the PEP joystick, tending to push the platform back away from the siren and effectively overcoming the PEP motor's ability to set the position of the platform. Attachment of the baffle to the front of the PEP chair was an attempt to minimize this problem.

*Sound-Attenuating Chamber.* During all training and testing phases, the PEP and the sirens were located inside of a 627.0 cm long x 284.0 cm wide x 200.0 cm high sound-attenuating chamber (Industrial Acoustics Company, Bronx, NY). All control and recording equipment (with the exception of B&K microphones, the microphone power supply, and video cameras) was situated immediately outside of this sound-attenuating chamber.

#### *Procedure and Data Analysis*

*Pre-Exposure Hearing Tests.* All subjects received two hearing batteries prior to being exposed to the siren. Each of the two sessions was comprised of the two individual tests discussed in the *General Methods and Procedures* section: (a) otoacoustic emissions, and (b) auditory brainstem response. The second of these two hearing batteries was conducted 1 to 5 days prior to being exposed to the siren.

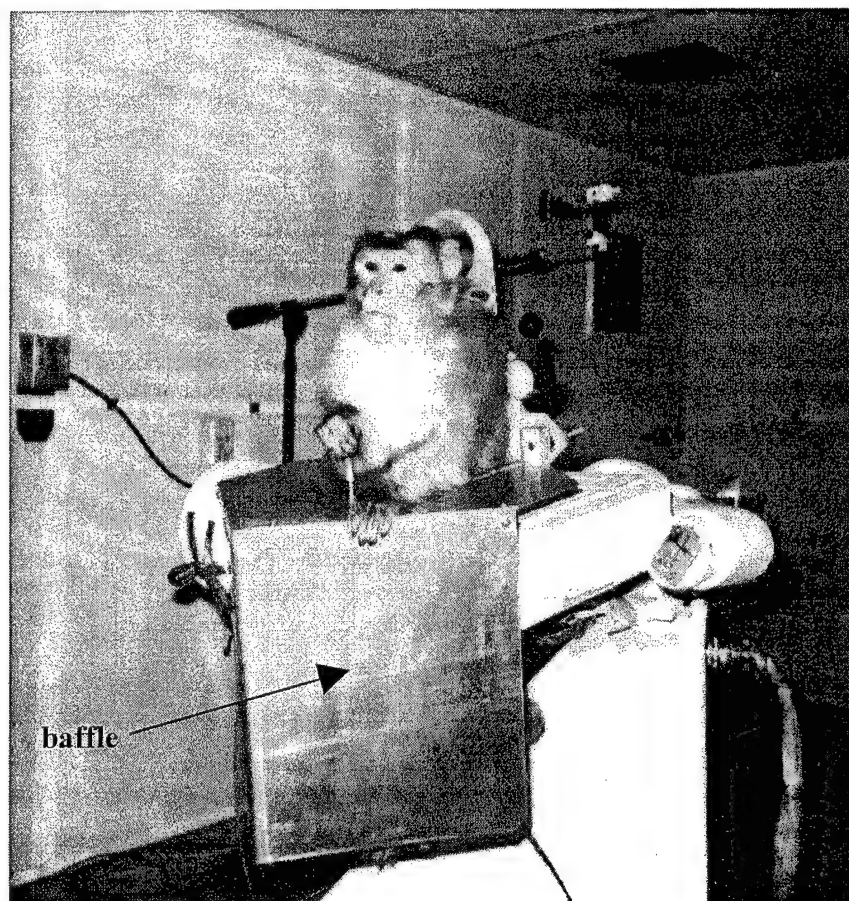


Figure 10. Rhesus subject operating Primate Equilibrium Platform with baffle attached to front of joystick platform

*Pre-Exposure PEP Training.* All 5 subjects received extensive re-training on the PEP task during the months prior to being exposed to the siren. The five PEP training sessions which immediately preceded the exposure PEP session were designated as the baseline PEP sessions. All baseline PEP sessions were 60 min in duration. For purposes of analysis, each 60-min baseline session was subdivided into 24 epochs of 2.5 min each. Shock frequency, mean chair position, and the standard deviation of chair position were calculated for each epoch as described in the *General Methods and Procedures* section.

*Exposure to Siren During PEP Task.* Each subject was exposed to the siren during a 60-min PEP session. During this exposure PEP session, shock frequency, mean chair position, and the standard deviation of chair position were calculated for each of the 24 2.5-min epochs (in a manner identical to their calculation during the baseline sessions). Further, chair standard deviation for each subject's exposure session was compared with chair standard deviation during the five baseline PEP sessions for that subject. More specifically, standard deviation values from the baseline sessions for a given subject were used to determine the range of normal performance for that subject by the method of simultaneous tolerance limits (see the *General Methods and Procedures* section for details). For 4 of the 5 subjects, the baffle was fixed to the front of the



PEP chair during the entirety of the PEP exposure session. For the fifth subject, it was not used. In addition, for 2 of the 5 subjects, joystick position, chair position, forcing function, and shocks were digitally acquired using WINDAQ data acquisition software as described in the *General Methods and Procedures* section.

During the first 5 to 22.5 minutes of each exposure PEP session, subjects were allowed to perform the task as they did during a baseline session. Following this period, subjects were exposed to the siren. Exposure conditions varied for the 5 subjects. All subjects were exposed to the low- rather than the high-frequency CADS. (Although plans called for the measurement of PEP performance during exposure to both the low- and the high-frequency siren, mechanical problems with the high-frequency siren prevented its use.) The number of times the siren was turned on during a PEP exposure session varied from three to seven times. The duration of each exposure was approximately 30 s. The siren beam director was employed during the exposure sessions of 3 of the 5 subjects.

Placement of the siren relative to the PEP also differed for the 5 subjects. For 2 of the 5 subjects, the front of the PEP was situated 68.6 cm directly in front of the low-frequency siren. This experimental setup, designated Setup A, is shown schematically in Figure 11. During testing for these 2 subjects, siren output was not recorded and digitized because all of the necessary hardware and software components were not yet in a fully functional state. For the remaining 3 subjects the PEP was situated in front and to right of the siren; that is, the front of the PEP was 76.3 cm in front of the siren and approximately 25° to the right of the siren's bore-sight. This experimental setup, designated Setup B, is shown schematically in Figure 12. In addition, during testing for these 3 subjects two B&K microphones were situated near the PEP in order to record the amplitude and frequency of the siren output. During each siren exposure, the acoustic output of the siren was captured by the recording microphones, and analyzed by the LabVIEW FFT program. Table 1 summarizes the differing conditions for the 5 subjects tested.

*Post-Exposure Hearing Tests.* All subjects received a hearing battery following their exposure to the low-frequency siren. In all but one case, this post-exposure hearing battery followed exposure by less than 2 hours. In the case of one subject, the hearing battery followed the exposure session by 96 hr. Each post-exposure hearing battery was comprised of the same two individual tests employed in the pre-exposure batteries.

## *Results and Discussion*

*PEP Task and Acoustic Measurements.* Figure 13 depicts the PEP performance of the 2 subjects run with Setup A (868Z, top panel; and 810Z, bottom panel). Figures 14 and 15 depict the PEP performance of the 3 subjects run with Setup B (898Z, Figure 14; 828Z, Figure 15, top panel; and 928Z, Figure 15, bottom panel). In overview, exposure to the low-frequency compressed-air-driven siren measurably affected the PEP performance of 3 of the 5 rhesus subjects: 868Z, 810Z, and 928Z. Thus, Figure 13 (top panel) shows standard deviation of platform position for 868Z for each of the 24 test epochs, including the 7 epochs during which the subject was exposed to the 1000-Hz siren signal. For 3 of those 7 exposure epochs, platform position exceeded the 99% upper confidence limit (the first, third, and sixth exposures). Similarly, Subject 810Z received five 1000-Hz exposures; platform position standard deviation

exceeded the upper confidence limit for each of the five epochs during which an exposure occurred (see Figure 13, bottom panel). Finally, Subject 928Z received one 1500-Hz

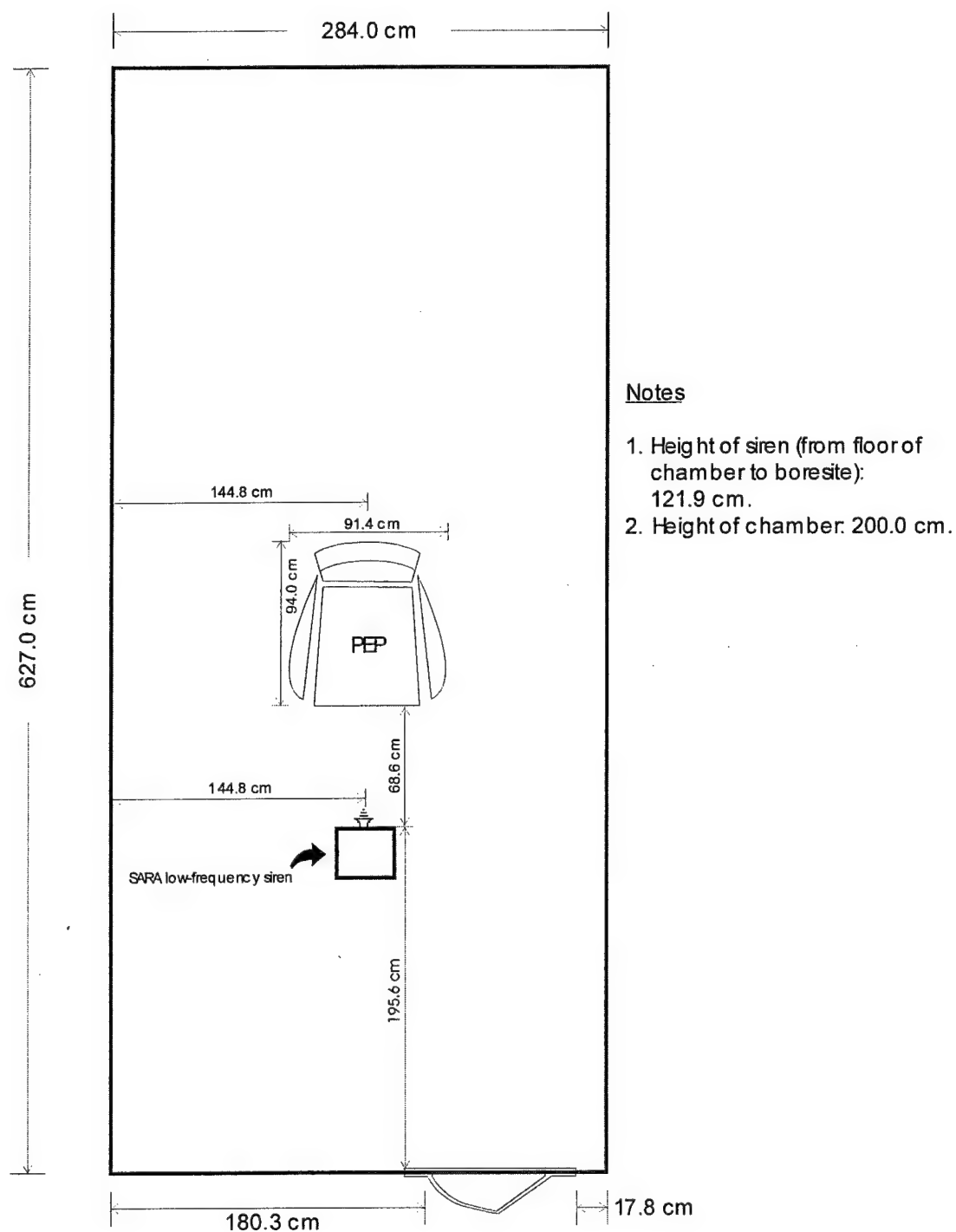
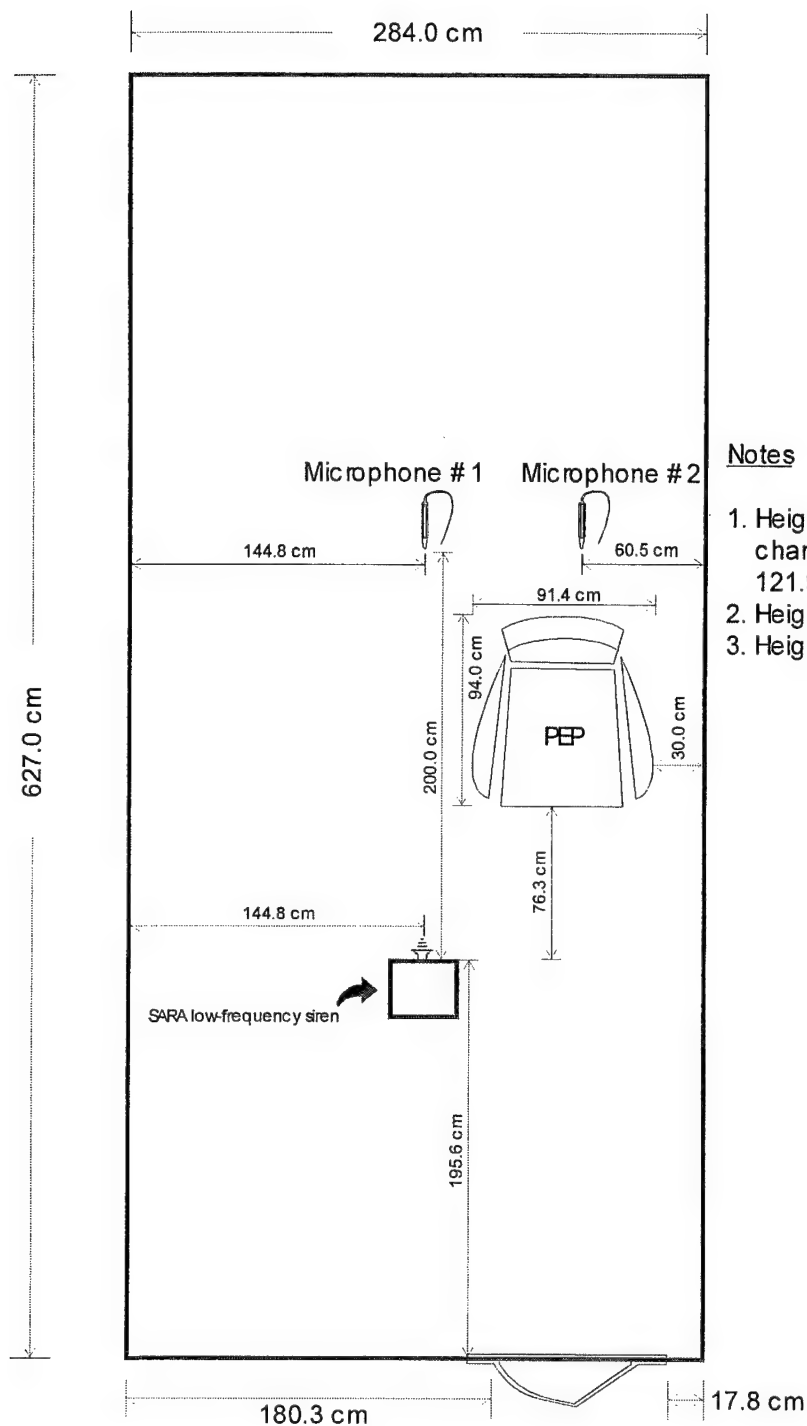


Figure 11. Experimental setup (Setup A) used with 2 of 5 rhesus subjects during exposure to compressed-air-driven siren.



#### Notes

1. Height of siren (from floor of chamber to boresite): 121.9 cm.
2. Height of microphones: 121.9 cm.
3. Height of chamber: 200.0 cm.

Figure 12. Experimental setup (Setup B) used with 3 of 5 rhesus subjects during exposure to compressed-air-driven siren.

Table 1. Experimental conditions for the 5 rhesus subjects exposed to the low-frequency compressed-air-driven siren.

Subject ID	Siren beam director employed?	PEP baffle employed?	PEP data collected with WINDAQ?	Siren amplitude, frequency data collected with LabVIEW?	Setup in sound-attenuating chamber	Number of siren exposures	Siren frequency during exposures (Hz)
868Z	no	no	yes	no	A	7	1000
810Z	no	yes	yes	no	A	5	1000
828Z	yes	yes	no	yes	B	5	500 (1 exposure), 1000 (2 exposures), and 1500 (2 exposures)
928Z	for 4 of 7 exposures	yes	no	yes	B	7	1000 (6 exposures) and 1500 (1 exposure)
898Z	yes	yes	no	yes	B	3	1500

exposure and six 1000-Hz exposures. An inspection of Figure 15 (bottom panel) shows statistically significant decrements in PEP performance during the first three exposures. In contrast, the PEP performance of Subjects 898Z and 828Z, as measured by platform position standard deviation, did not significantly differ from their baseline performance during any of epochs on which they were exposed (see Figure 14 and Figure 15, top panel, respectively).

Further inspection of Figures 13-15 also indicates a tendency for siren exposures to result in marginally poorer PEP performance, even when this decrement does not exceed the 99% confidence limit. The standard deviation of platform position shows a marked tendency to be greater during exposure epochs as compared to epochs that immediately precede or follow the exposure epoch. For example, platform position standard deviation for Subject 868Z for Epoch 18 (during which the subject was exposed to a 1000-Hz signal) was 3.77°. In contrast, the platform standard deviations for Epochs 17 and 19 were 1.86° and 1.65°, respectively. This tendency for platform position standard deviation during exposure epochs, although not exceeding the 99% confidence limit, to nevertheless exceed that of the immediately adjacent epochs, was not tested statistically. It was, however, quite pronounced, occurring on 13 of 15 occasions (see Figures 13-15).

The general conclusion that PEP performance is adversely affected by exposure to the low-frequency siren is buttressed by an examination of the PEP data as recorded using the WINDAQ application. (Such data were available for only 2 of the 5 subjects, 810Z and 868Z; see Table 1.) Figure 16 (upper panel) illustrates the PEP performance for 810Z for an approximately 9.2-s



period of time preceding the first of five 1000-Hz siren exposures. During this period, the

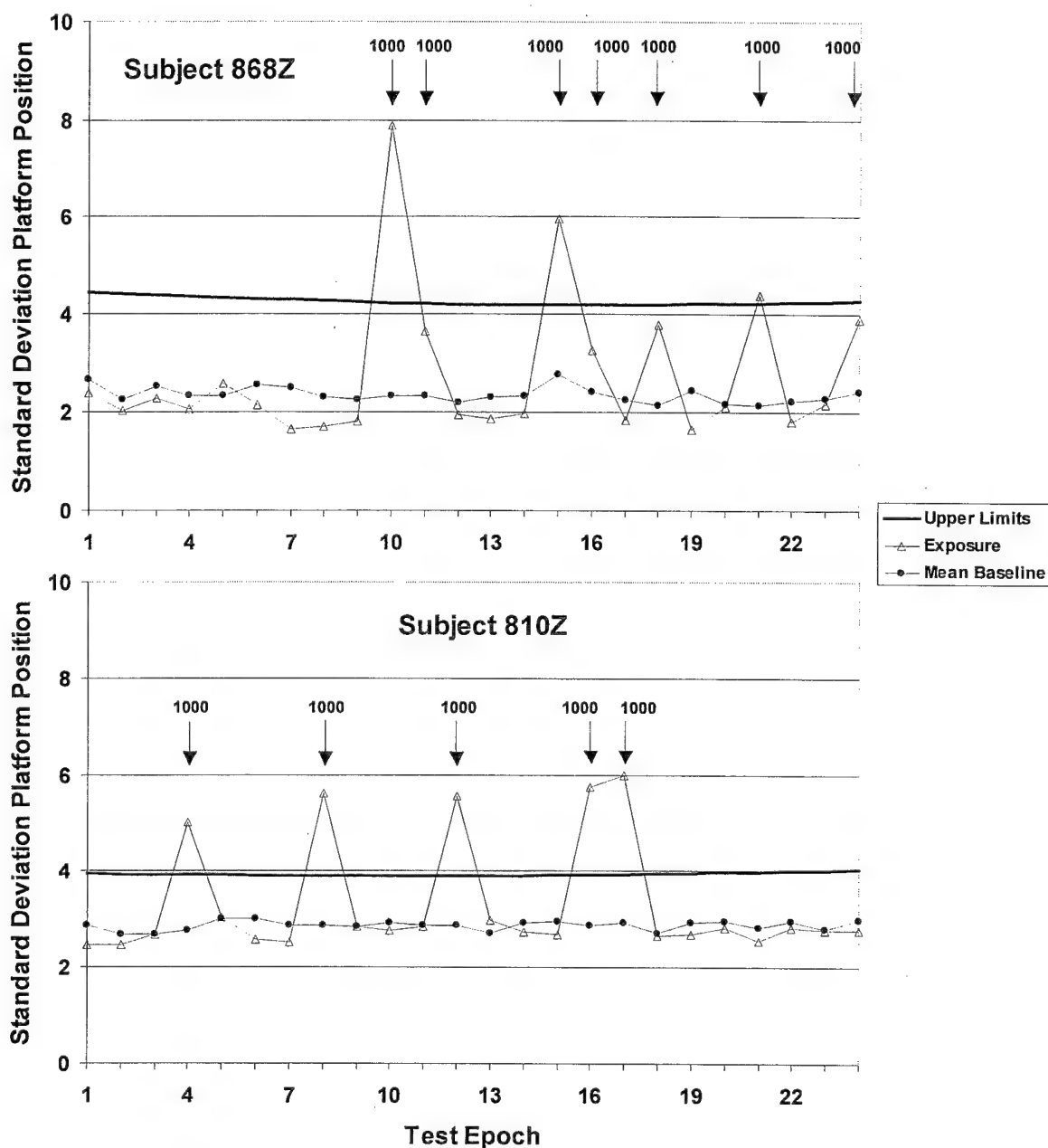


Figure 13. PEP performance of 2 of 5 rhesus subjects during exposure to the low-frequency compressed-air-driven siren. Both subjects were exposed using Setup A. (Arrows and numbers above the arrows indicate epochs during which the siren was on and the frequency at which the siren was set, respectively.)

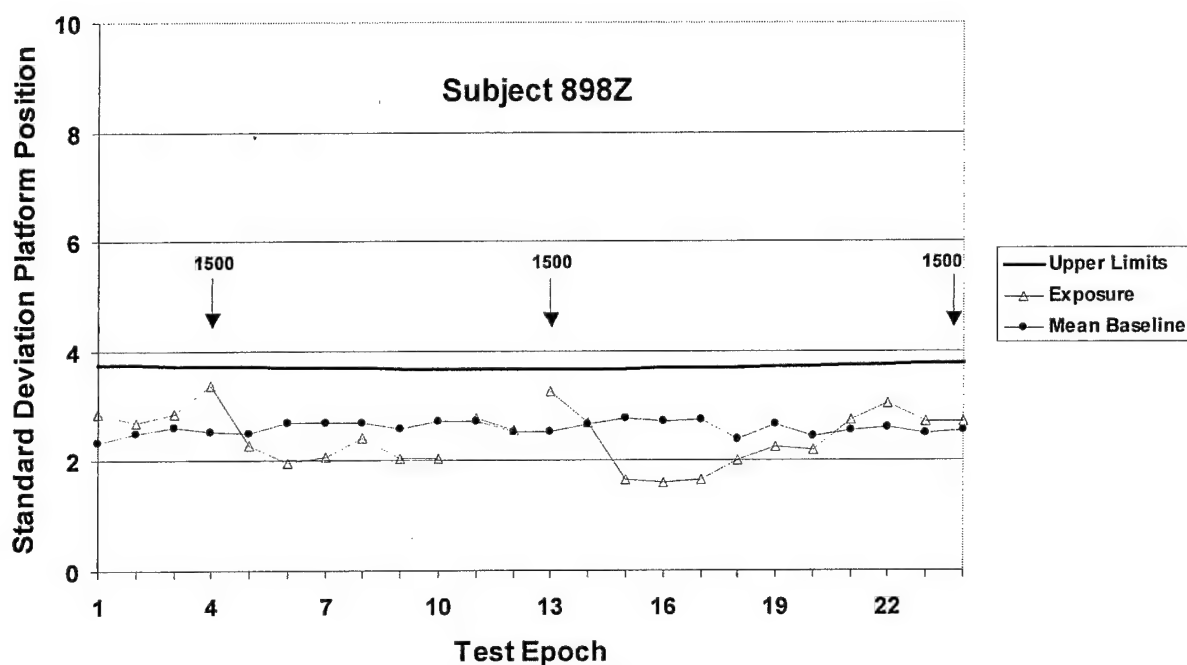


Figure 14. PEP performance of 1 of 5 rhesus subjects during exposure to the low-frequency compressed-air-driven siren. Subject was exposed using Setup B. (Arrows and numbers above the arrows indicate epochs during which the siren was on and the frequency at which the siren was set, respectively.)

subject was performing well within the task requirements, maintaining a relatively low platform standard deviation. A few points are noteworthy. First, inasmuch as chair position did not exceed the position limits of  $\pm 15^\circ$ , no shocks were delivered to the subject as seen on the bottom trace of the panel. Second, the trace for joystick position closely approximates that for the forcing function (second and third traces, respectively), with each being approximately  $180^\circ$  out of phase with the other.

This is expected in a well-performing subject: The forcing function refers to the bounded stochastic process which generates pseudorandom perturbations in platform position; the subject employs the joystick to counter these changes, the end result being the actual platform position. The fact that joystick position is  $180^\circ$  out of phase with forcing function, as opposed to being in phase, is a consequence of the electronics controlling the PEP system, and is of no special theoretical significance.

The bottom panel of Figure 16 depicts the same four traces for the first 8.5 s of an approximately 30-s, 1000-Hz siren exposure for the same subject. With siren onset, the aforementioned relationship between forcing function and joystick position largely disappears, as both chair and joystick position become much more erratic. Note also that because the platform position falls outside of the  $\pm 15^\circ$  limits, the subject received five shocks.

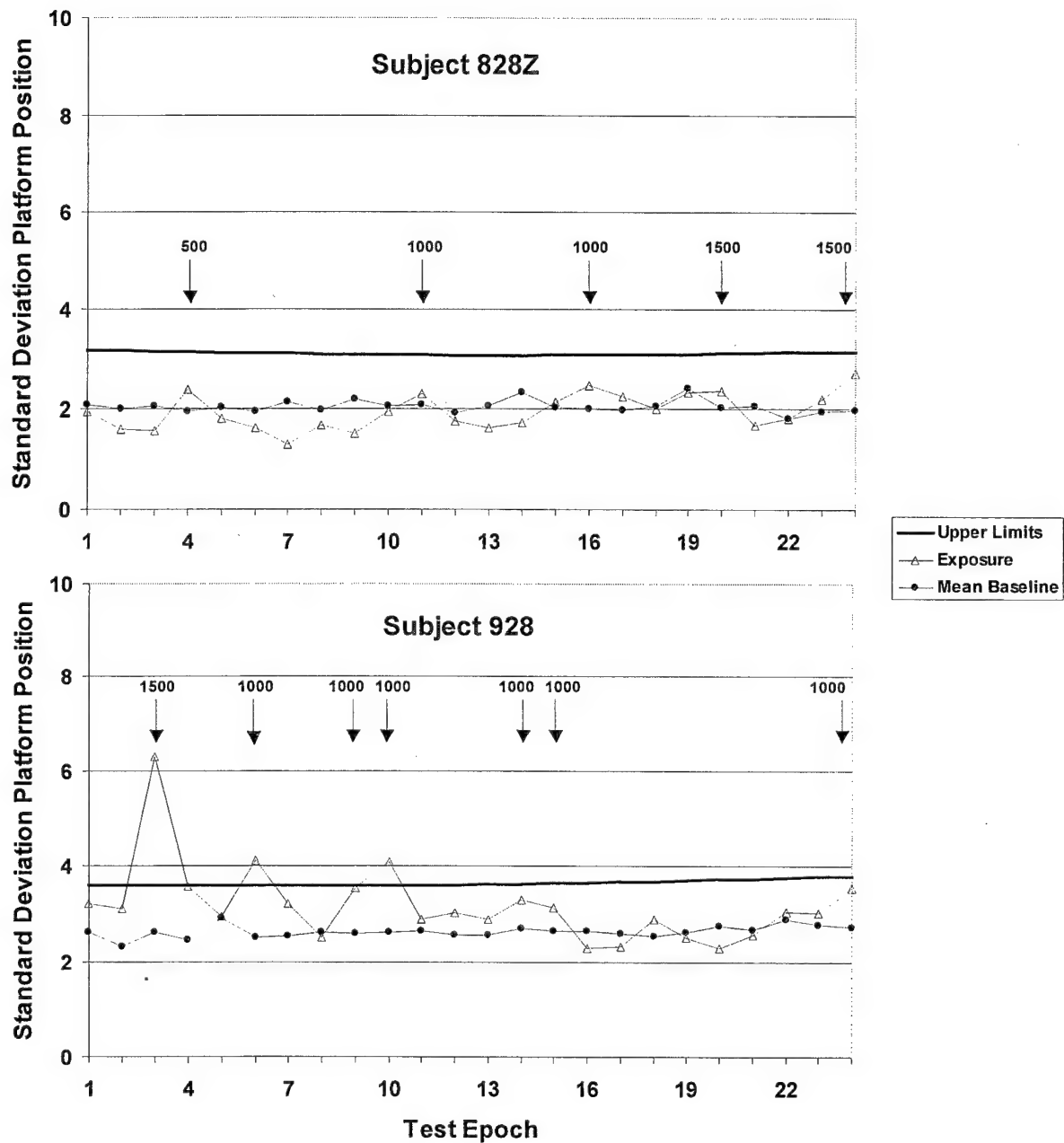


Figure 15. PEP performance of 2 of 5 rhesus subjects during exposure to the low-frequency compressed-air-driven sirens. Subjects were exposed using Setup B. (Arrows and numbers above the arrows indicate epochs during which the siren was on and the frequency at which the siren was set, respectively.)

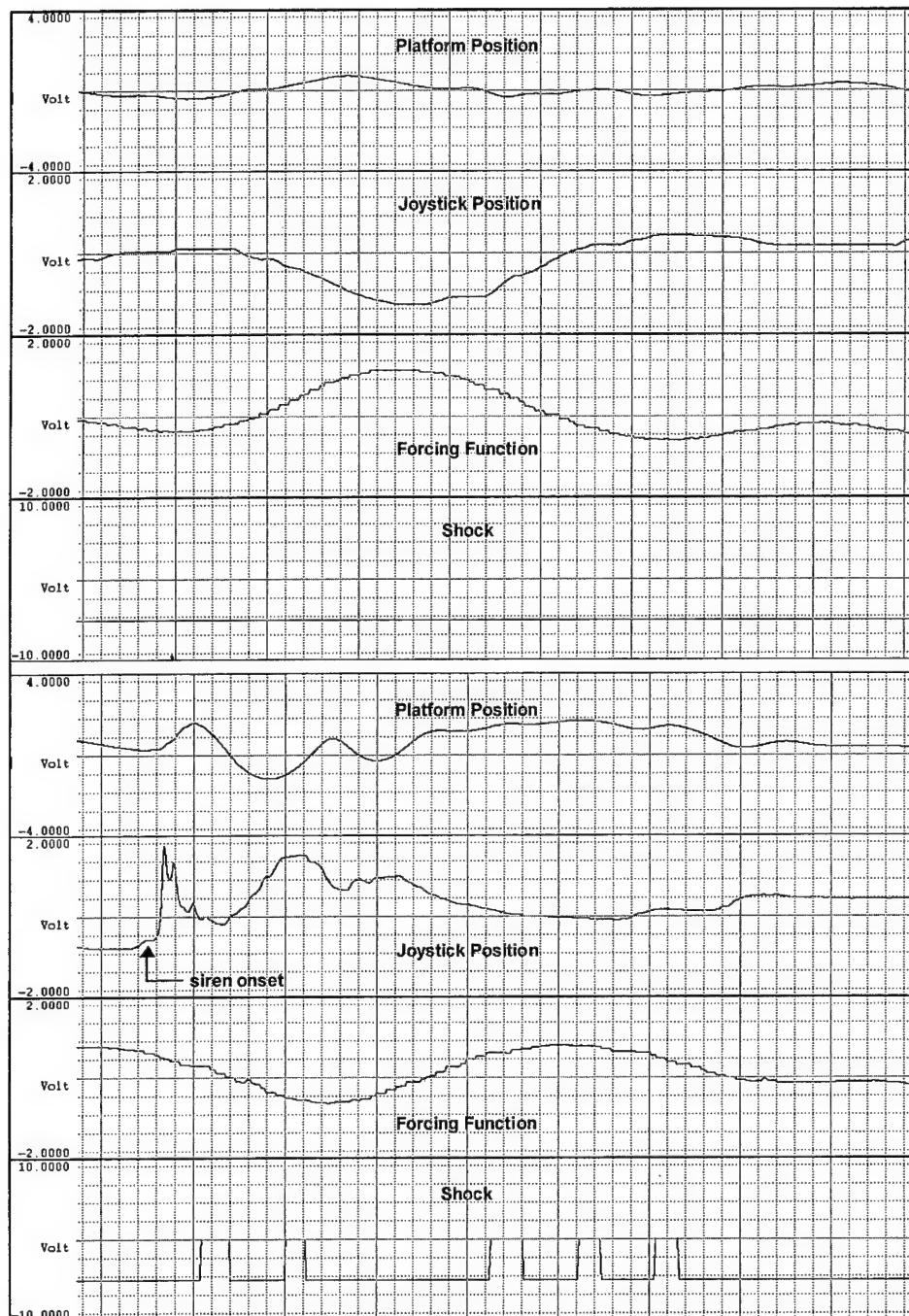


Figure 16. PEP performance (platform [chair] position, joystick position, forcing function, and shock) for Subject 810Z prior to the onset of the low-frequency siren (top four traces) and during the siren exposure (bottom four traces). (Siren onset indicated by arrow in trace for joystick position. Grid lines along x-axis are in increments of 200 ms.)

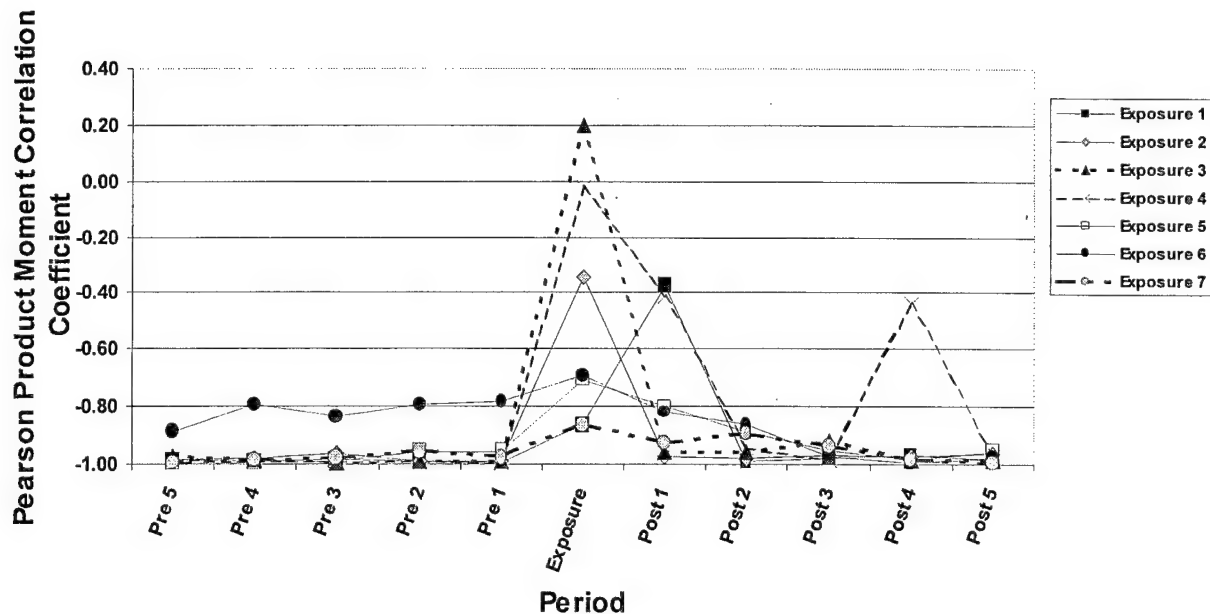


Figure 17. Pearson product moment correlation coefficients between joystick position and forcing function before, during, and following exposure of Subject 868Z to the low-frequency siren. (For all  $r$ 's,  $p < .01$ .)

This relationship between joystick position and forcing function is summarized in Figures 17 and 18 (for Subjects 868Z and 810Z, respectively). Each figure details a sequence of Pearson product moment correlation coefficients between forcing function and joystick position over a period ranging from before to after each of the siren exposures. Each coefficient was calculated for a period of time equal in duration to that of the corresponding siren exposure. (E.g., the duration of Exposure 1 for 868Z was 12.15 s. The coefficients reported for the five periods preceding [Pre 5 through Pre 1] and five periods following [Post 1 through Post 5] this exposure are each based on the same number of data points as used in the calculation of the exposure coefficient and hence represent periods of time equal in duration.)

The general pattern evident is for correlation coefficients to approach  $-1.0$  during the periods leading up to the exposure, which one would expect given the aforementioned relationship between the two variables during periods when subjects are performing well. Although not true in every case, coefficients tend to maximally depart from this plateau during the exposure period itself and to return to near  $-1.0$  sometime during the ensuing periods. This return to values representing good task performance sometimes occurs immediately (i.e., at Post 1), but sometimes takes one or more periods. Correlation coefficients during the exposure period fall in the range of approximately  $-.87$  to  $.20$ .

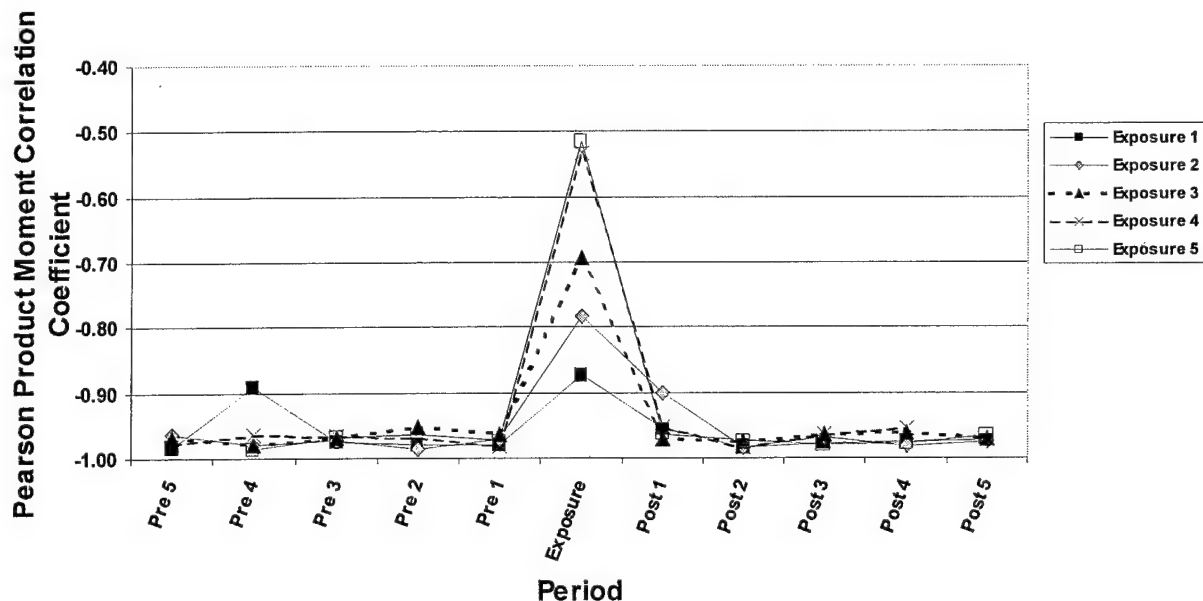


Figure 18. Pearson product moment correlation coefficients between joystick position and forcing function before, during, and following exposure of Subject 810Z to the low-frequency siren. (For all  $r$ 's,  $p < .01$ .)

A number of other conclusions can be drawn from the PEP data. First, there appears to be no definitive effect of siren frequency on PEP behavior. Thus, over the course of the five test sessions, subjects were exposed to a 1000-Hz signal from the siren on 20 occasions; a statistically significant performance decrement was recorded on 10 of those exposures. Subjects were exposed to the 1500-Hz signal on 6 occasions with a statistically significant decrement resulting from 1 of those exposures. The frequencies in the resulting 2 x 2 contingency table do not significantly differ from what would be expected from random occurrence (Fisher exact probability test,  $p > .05$ ).

Alternatively, there does appear to be an effect of PEP placement on PEP performance. More specifically, 2 of the 5 subjects were tested in Setup A, while the remaining 3 subjects were tested using Setup B (see Table 1). Of the 12 Setup A exposures (Subjects 810Z and 868Z), 8 resulted in PEP performance decrements as measured by platform position standard deviation. In contrast, only 3 of the 15 Setup B exposures (Subjects 898Z, 828Z, and 928Z) resulted in a performance decrement. The frequencies in the resulting 2 x 2 contingency table significantly differ from what would be expected from random occurrence (Fisher exact probability test,  $p < .05$ ).

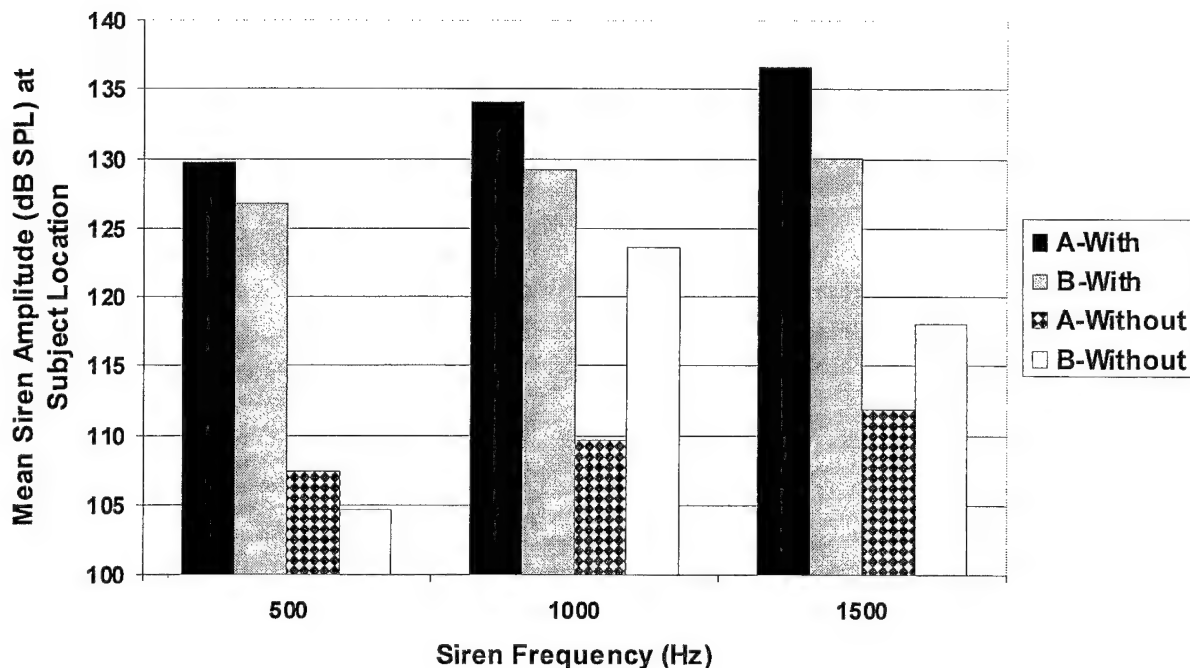


Figure 19. Mean amplitude (dB SPL) of the low-frequency siren used with and without the beam director at two subject locations (Setup A and B).

The interpretation of this last finding is made somewhat problematic given that a number of factors covary with placement of the PEP apparatus. First, virtually all of the Setup A exposures occurred without benefit of the siren beam director, while the majority (79%) of the Setup B exposures did employ the beam director. One immediate effect of both PEP placement and beam director is on siren amplitude measured at the approximate subject location (i.e., seated in the PEP). Figure 19 shows mean amplitudes levels at three siren frequencies (500, 1000, and 1500 Hz) under four sets of conditions: Setup A/with beam director, Setup B/with beam director, Setup A/without beam director, and Setup B/without beam director.<sup>1</sup> The amplitudes more or less conform to expectations given the function of the beam director. Thus, in the two conditions where the beam director is not in use, amplitudes at Point B (about 25° degrees off the center axis of the siren bore-sight; see Figure 12) tend to exceed those for Point A (directly on the center axis of the siren bore-sight; see Figure 11). Specifically, Point B amplitudes exceed those for Point A at 1000 and 1500 Hz (by 14.0 and 6.2 dB, respectively). (For reasons that are not clear, this pattern does not hold at 500 Hz, where the amplitude at Point A is slightly higher than that at B [mean difference of 2.8 dB].)

As noted previously, the beam director was designed to focus more narrowly the acoustic energy of the siren along the bore-sight and concomitantly suppress the side-lobes evident without its use. Figure 19 confirms that to some extent it was effective in doing so. That is, when the beam director was in use, mean amplitudes at Point A (directly in front of the siren)

<sup>1</sup> The mean sound level values shown in Figure 19 were not all obtained while subjects were actively engaged in the PEP task. This was due in part to the fact that the requisite hardware and software were not available at the time the Setup A subjects were run (see Table 1).

exceeded those at Point B (approximately 25° off center) for all three of the frequencies (mean differences of 3.0, 4.9, and 6.5 dB for 500, 1000, and 1500 Hz, respectively). Somewhat surprisingly, in the case where the beam director was employed, mean amplitudes at Point B (as well as A) exceeded all of the calculated means for exposures not using the director.

Further consideration of Figure 19 reveals something of a paradox: All of the Setup A subjects were exposed to a siren without benefit of the beam director (see Table 1). Thus, the approximate mean amplitude for these subjects (collapsed across the three frequencies) was approximately 109.6 dB. As noted previously, almost all of the Setup B subjects were exposed to a siren fitted with the beam director. That is, the approximate mean amplitude to which these subjects were exposed (again collapsed across the three frequencies) was 128.7 dB. Yet, as noted before, the siren appeared maximally effective for the Setup A subjects (when the mean amplitudes were less).

One hypothesis to account for this paradox is that amplitude per se was less important in impacting PEP performance than was the volume of air emitted by the device. Thus, airflow ( $\text{m}^3/\text{s}$ ) was judged by all observers to be maximal when the PEP apparatus was positioned at Point A, directly in front of the siren, as opposed to Point B, where it was approximately 25° off of the bore-sight of the siren. Although, unfortunately, no direct measurements of airflow were made during the siren exposures, there is indirect evidence that siren airflow was indeed instrumental in degrading PEP performance. Subject 868Z was the only subject to perform the PEP task without use of the baffle fitted to the front of the platform (see Table 1). As noted above, without its use the airflow from the siren "caught" the undersurface of the shelf housing the PEP joystick, tending to push the platform back away from the siren and effectively overcoming the PEP motor's ability to set the position of the platform. Attachment of the baffle to the front of the PEP chair was an attempt to minimize this problem. Figure 20 shows the moment-to-moment position of the platform during one of the exposures for 868Z. The plateau (at approximately -4 V) evident during a large portion of the exposure reflect the fact the airflow "pinned" the platform back in a direction away from the siren. In contrast, Figure 16 (bottom panel) shows the moment-to-moment platform position during a 1000-Hz exposure for Subject 810Z, while operating the PEP with the baffle. While platform position is still relatively erratic when contrasted with pre- and post-exposure periods, the trace shows that the airflow is no longer substantial enough to pin back the platform, thus allowing the subject to control its position in the pitch plane.

*Hearing Tests.* Exposure to the low-frequency CADS had no measurable impact on the hearing of any of the 5 subjects. ABRs conducted in the aftermath of the CADS exposures were, in all respects, indistinguishable from those collected prior to exposure. That is, pre- and post-exposure thresholds were identical for both of the stimuli used to elicit ABRs (clicks and tone bursts). For all subjects, click stimuli produced replicable responses down to 10 dBnHL in both the right and left ear (representing normal peripheral sensitivity). For all subjects, 500 Hz and 4kHz tone bursts produced replicable responses down to 20-40 dBnHL bilaterally (again, representing normal peripheral sensitivity).



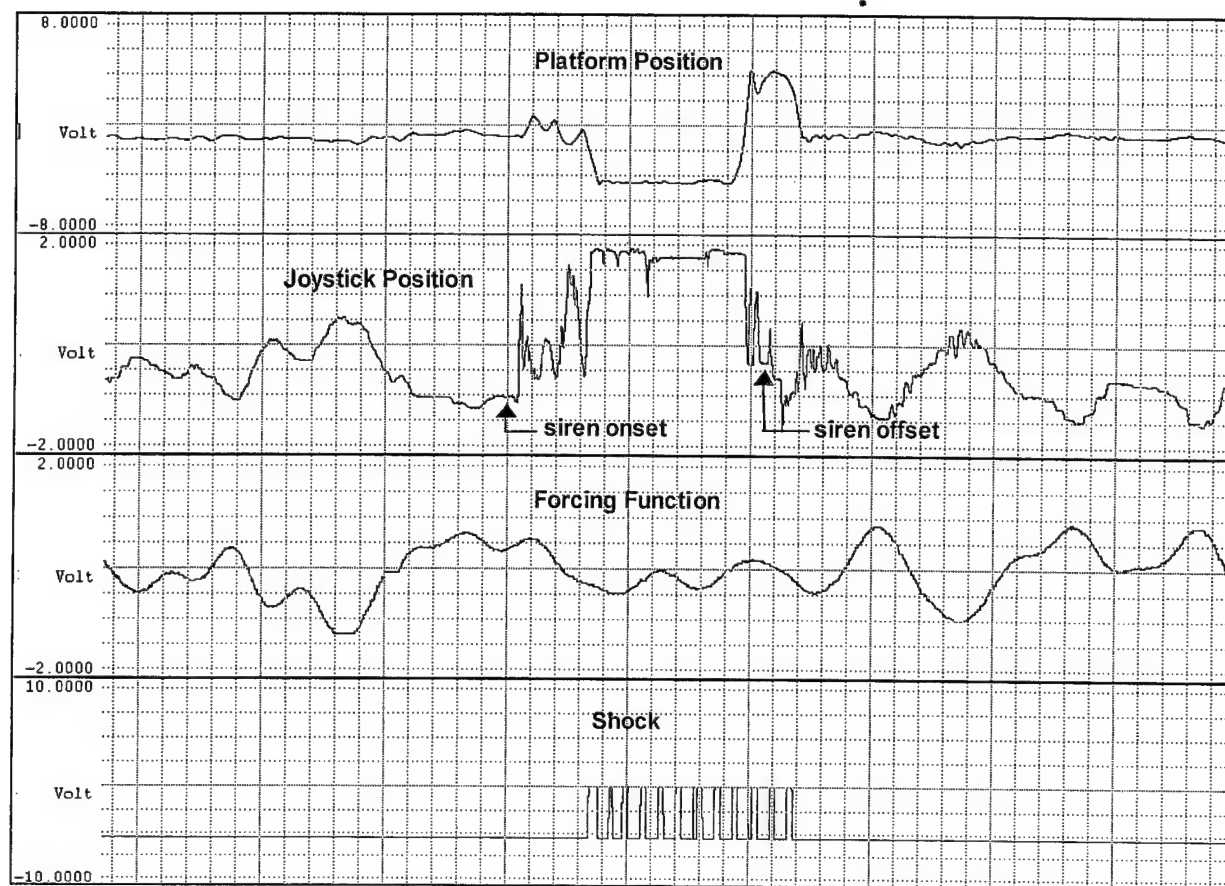


Figure 20. PEP performance (platform [chair] position, joystick position, forcing function, and shock) for Subject 868Z prior to, during, and after exposure to the low-frequency siren. (Siren onset and offset indicated by arrows in trace for joystick position. Grid lines along x-axis are in increments of 1200 ms.)

DPOEA amplitudes for all 5 subjects both prior to and following exposure to the CADS ranged from 5 to 20 dB SPL for both right and left ear, indicating a normal response from the outer hair cells. Figure 21 depicts the pre- and post-exposure DPOAE amplitudes for Subject 868Z. (Figure 21 contrasts DPOEA amplitudes with the “noise floor,” which is calculated as the root mean square of values for frequencies adjacent to the intermodulation product. If the distortion product is significantly higher than the noise floor, as in Figure 21, normal cochlear function is inferred. If the distortion product overlaps the noise floor, then outer hair cell damage has occurred.)

In summary, the low-frequency compressed-air-driven sirens significantly impacted the PEP performance of some rhesus subjects during some (but not all) of the exposures. The operation of the siren had no effect on either the short- or long-term hearing of the subjects. The effect of the sirens on PEP performance did not significantly vary as a function of siren frequency. However, it seems doubtful that the effect was mediated by the acoustic properties of the siren signal per se. Rather, we conclude that the effects were the result of the substantial air flow

created by the siren, pushing against the front of the chair to the extent that optimal operation of the apparatus was made difficult for the rhesus subjects.

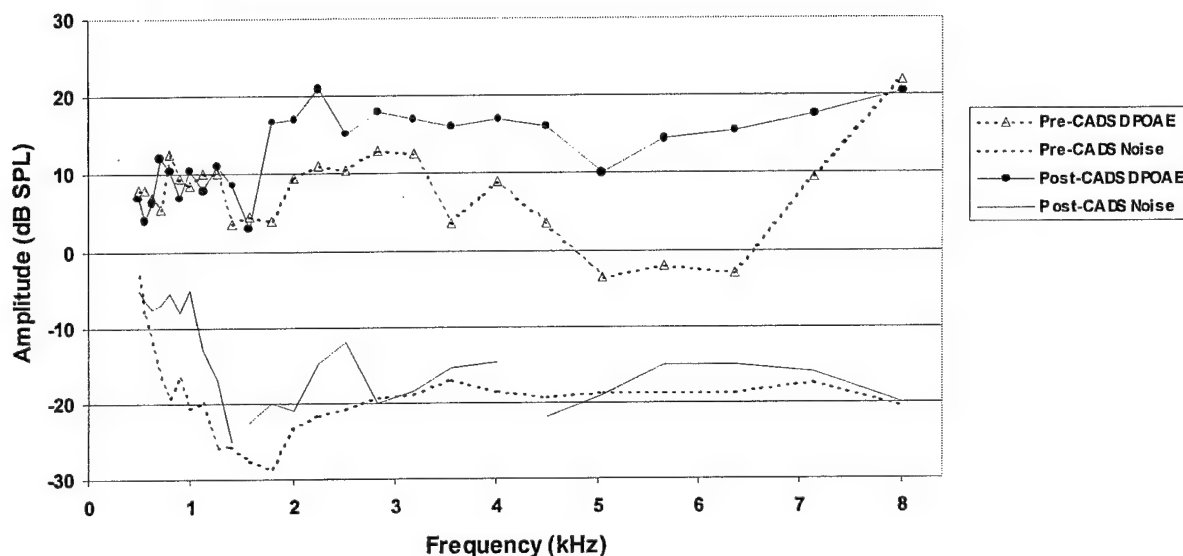


Figure 21. Amplitude of distortion product otoacoustic emissions (DPOAE) and noise floor prior to and following exposure to compressed-air-driven siren for left ear of Subject 868Z.

## DISMOUNTED BATTLEFIELD BATTLE LABORATORY SIREN

### Subjects

Subjects were 2 adult male goats (*Capra hircus*) ranging in weight from approximately 65 to 75 kg. Subjects ranged in age from approximately 6 to 8 years at the time of testing. The subjects were housed and maintained at Kirtland Air Force Base, NM, as described in the *General Methods and Procedures* section.

### Apparatus

**Acoustic Source.** The Dismounted Battlefield Battle Laboratory (DBBL) siren was designed and built by SARA. The DBBL siren was designed to utilize the conversion efficiency and high-density energy storage of chemical combustants to provide sound energy with 95% or more of the acoustic energy on the fundamental frequency (Sollee, 1995). Gaseous methane mixed with oxygen and nitrogen served as the combustants. The thermal energy resulting from the combustion of the gases was utilized to vaporize water injected into the combustion chamber, thus increasing the volumetric flow and the acoustic output of the device. Water injection reduced the exit temperature of the gases, thereby decreasing the acoustic impedance mismatch

between the hot gases and the ambient atmosphere. Water injection also reduced the need for external cooling devices. Water and carbon dioxide were the exhaust products when combustion was complete, while carbon monoxide was a potential by-product when combustion was incomplete. Exhaust temperatures were on the order of 428° C; the exhaust plume was dissipated within 2 m of the device. Similar to the CADS, the acoustic power of the DBBL siren was theorized to be a nonlinear function of the volumetric flow of the gases and the size and number of holes in the stator and rotor. The frequency of the sound generated was a function of the number of holes in the stator/rotor and the speed with which the rotor was spun. Figure 22 shows a schematic of the DBBL siren.

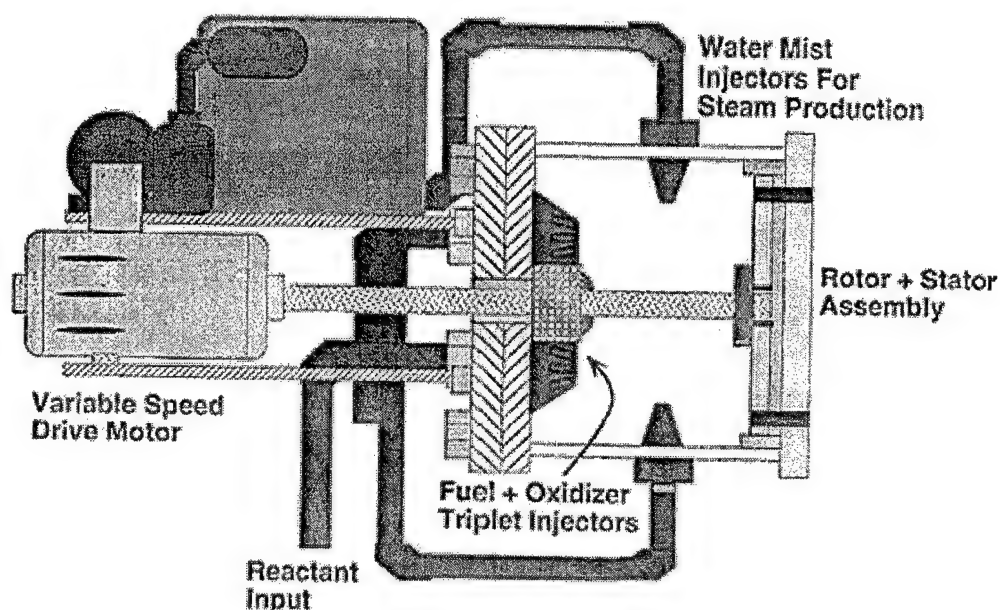


Figure 22. Schematic of the Dismounted Battlefield Battle Laboratory siren.

Prior testing of the siren indicated the presence of significant acoustic side lobes. Specifically, the maximal intensities were located approximately 60° on either side of the siren bore-sight. A beam director, designed to suppress these side-lobes and consequently increase power on the bore-sight, could be attached to the front of the siren. The beam director also contained the siren's exhaust plume. Figure 23 shows a side view of the DBBL siren (mounted on a trailer) fitted with the beam director. Figure 24 shows the front of the DBBL siren without the beam director.

*Panel-Pressing Equipment.* A panel-press device, designed by Whitmore Enterprises (San Antonio, TX) for use by goats and described in detail in the *General Methods and Procedures* section, was employed.

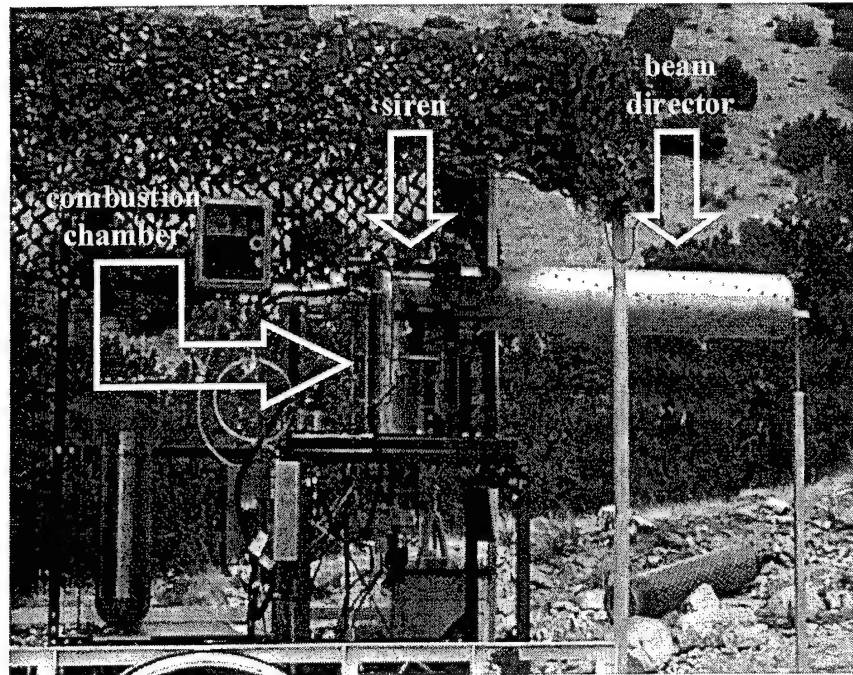


Figure 23. Side view of the Dismounted Battlefield Battle Laboratory siren fitted with the beam director.

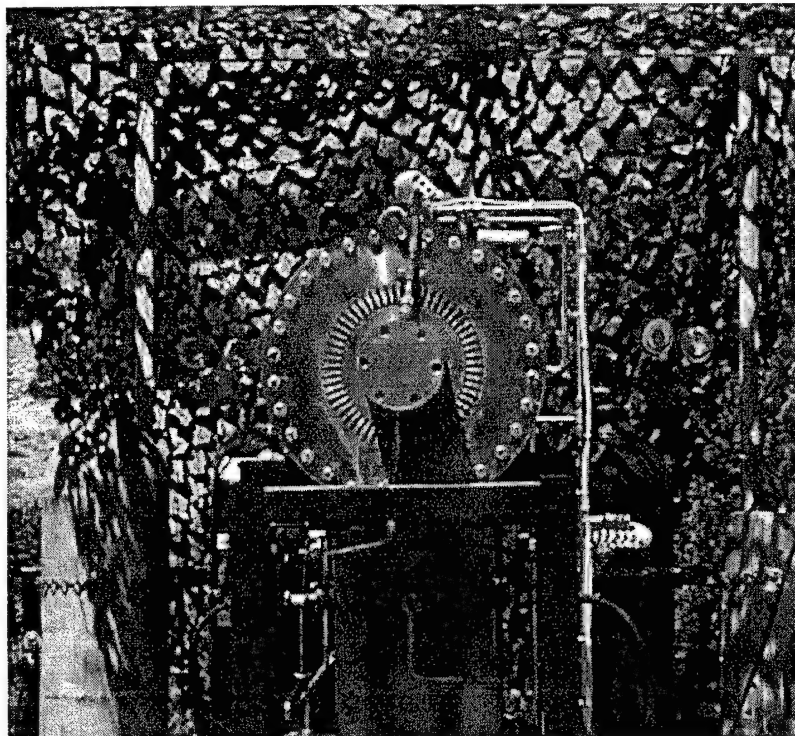


Figure 24. Front view of the Dismounted Battlefield Battle Laboratory siren (without the beam director attached).

## Procedure and Data Analysis

**Pre-Exposure Panel-Press Training.** Prior to testing with the DBBL siren, both subjects — 226 and 276 — had received extensive training with the panel-press apparatus. At the conclusion of training, both subjects pressed vigorously at a steady and reliable rate. A final training session was conducted for each subject approximately 48 hr before they were exposed to the siren.

**Exposure to Siren.** The DBBL combustion-driven siren was situated outdoors in a box canyon behind the High Energy Research and Test Facility (HERTF) of the Directed Energy Directorate, Air Force Research Laboratory, Kirtland Air Force Base, NM. The siren was mounted on a trailer. Equipment problems with the DBBL siren prevented use of the beam director during the testing to be described.

Figure 25 shows a schematic of the experimental setup. Because the beam director was not employed, the siren's bore-sight was directed  $60^\circ$  to the right of the subject panel-press apparatus; in other words, the siren's maximal amplitudes were located at or near the panel-press device where the subject was responding for food.

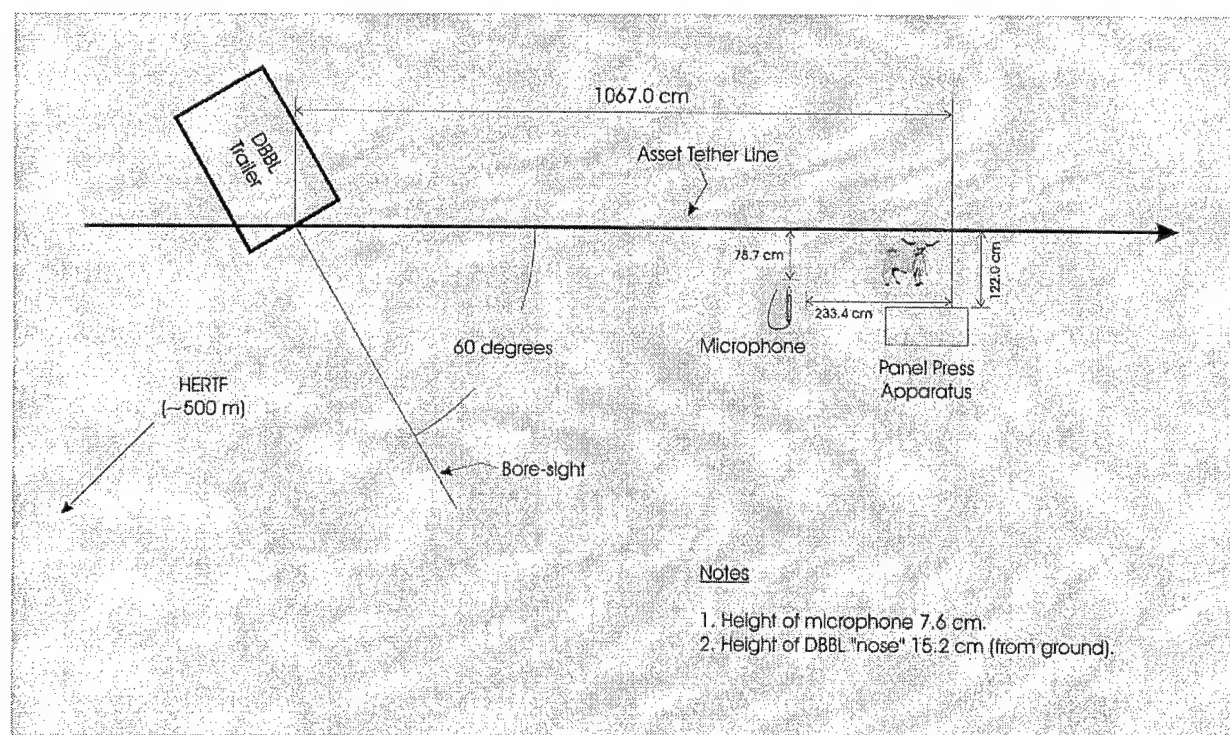


Figure 25. Experimental setup used with 2 goats during exposure to the Dismounted Battlefield Battle Laboratory siren (without beam director).

Each subject in turn was fitted with a harness. A metal chain attached the subject's harness to a wire tether approximately 30 m in length and approximately 2.5 m above the ground. This tether allowed the subject to move freely from a point near the siren, to the front of panel-press apparatus, and approximately 20 m beyond the panel-press device (i.e., approximately 30 m away from the siren). Once fitted with harness and tethered, each subject was allowed to freely panel press for food. Panel pressing throughout the experimental session was rewarded on a fixed-ratio 3 reinforcement schedule; every third response was rewarded with approximately 20 g of food. The occurrence and timing of panel-press responses was recorded by videotape.

Following an initial period of approximately 50-100 s, each subject was exposed to the DBBL siren a total of three times. For all of the exposures, the output frequency of the siren signal was set at 4000 Hz and the siren amplitude was set at maximum. Exposures were separated from one another by an average duration of 56 s (range = 16 to 97). The mean exposure duration was 13 s (range = 12 to 16). The acoustic intensity measurements during each of the siren exposures were acquired via a Brüel & Kjær (B&K) Model 4136A microphone situated near the panel-press apparatus and 833.6 cm from the siren (see Figure 25). The output of the microphone was amplified by a B&K microphone preamplifier (Model 2633) and a B&K Model 5935 Dual Microphone Supply. The output of the Dual Microphone Supply was digitized, displayed, and analyzed by an in-house LabVIEW program (see *General Methods and Procedure* for program details).

### *Results and Discussion*

*Acoustic Measurements.* Figure 26 depicts a representative FFT for one of the six siren

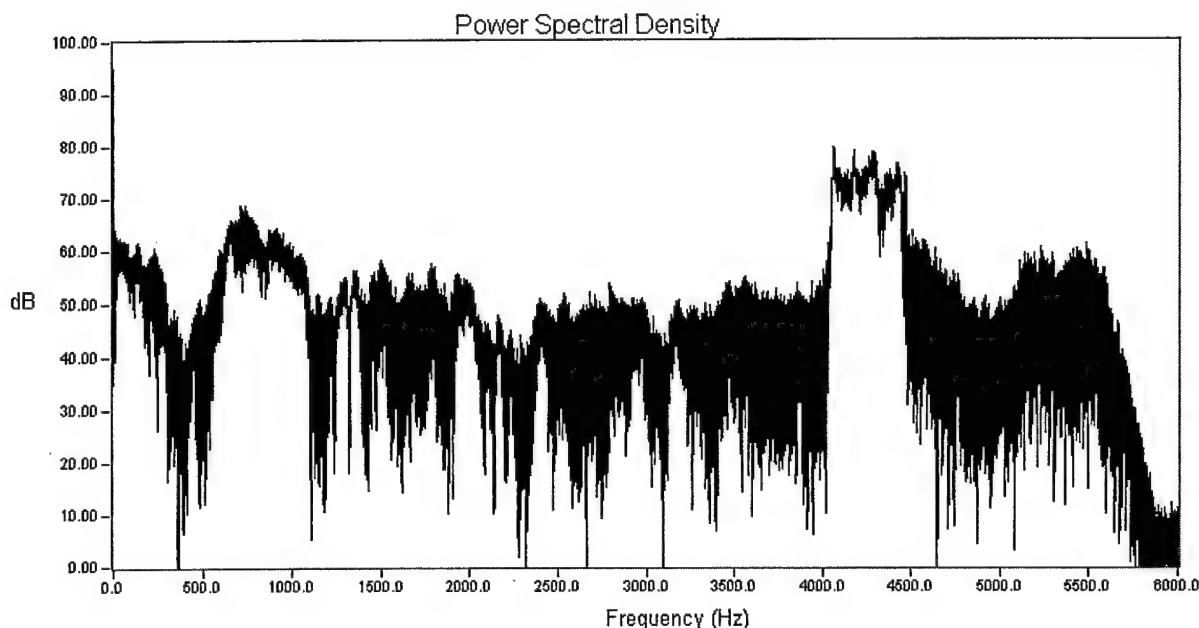


Figure 26. A representative FFT produced by the signal from the Dismounted Battlefield Battle Laboratory siren.



exposures. Several features are noteworthy. First, although operators specified an output frequency for the device of 4000 Hz, the measured frequency of the device varied significantly from exposure to exposure. The mean frequency was 4217.6 (range = 3931.6 to 4549.6). Second, the stated intention of the DBBL siren, as noted above, was to produce sound energy with 95% or more of the acoustic energy on the fundamental frequency. Unfortunately, this goal was not achieved. The mean amplitude at the fundamental over all six exposures was only 86.4 dB (range = 79.8 to 93.0). (The overall amplitude of the signal was more intense, of course. Based on an imprecise estimate of the RMS value of the acoustic signal, overall amplitude was estimated to be in the range of 115 dB.) Finally, each time the siren was operated, the signal was preceded by a momentary, explosive “pop” caused by the initial combustion of the gases used in producing the siren’s acoustic energy. The amplitude of this pop was substantially higher than that of the “sustained” acoustic signal that followed. Figure 27 depicts the time course (signal amplitude in volts versus time) of a typical signal, including the initial pop.

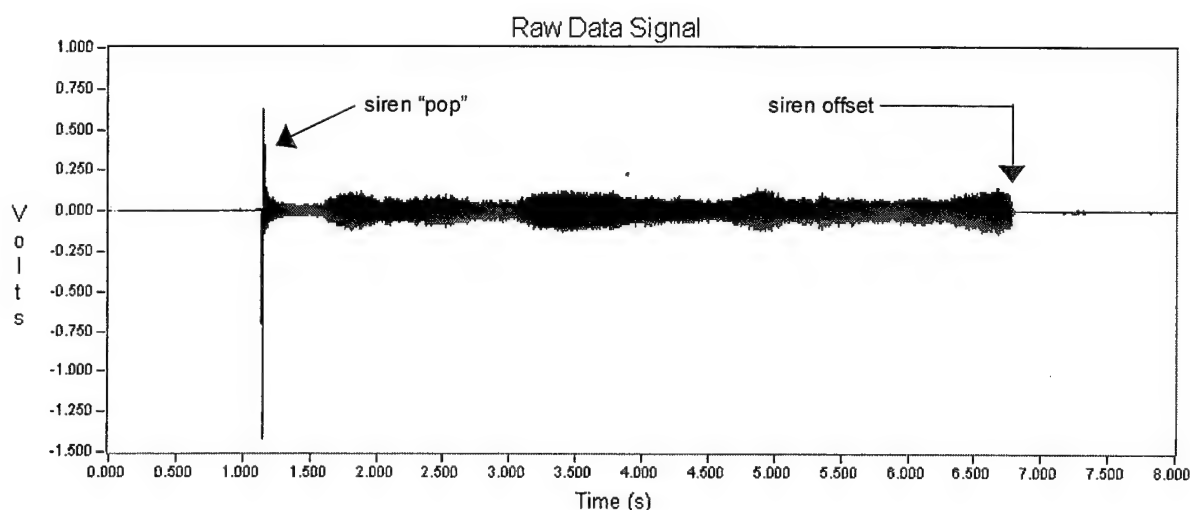


Figure 27. Output of the Dismounted Battlefield Battle Laboratory siren in the time domain (signal amplitude in volts as a function of time in s).

*Subject Behavior.* In the case of Subject 226, the onset of the siren for the first of three exposures produced an immediate and marked startle response with the subject moving a short distance (1-2 m) away from the panel-press apparatus (and further away from the siren). The subject returned to the panel-press apparatus almost immediately after the offset of the siren and recommenced panel pressing. Both the second and third exposures also produced an initial startle reaction, although these responses appeared milder than that which occurred during the first exposure. In addition, during the second and third exposures the subject did not leave the vicinity of the panel-press device, but instead continued to operate the manipulandum and consume food, albeit at a somewhat reduced rate. Figure 28 shows the panel press rates (number of presses per s) for Subject 226 during each of the three exposures and for the time periods which immediately preceded each of the exposures.

The behavior of subject 276 was very similar to that displayed by 226. The siren's onset during Exposure 1 produced a relatively pronounced startle response, resulting in the animal turning away from siren (but not moving away from the panel-press device). This response was not long lasting, however; before the offset of the siren, the subject had begun to eat from the food cup (although he did not have the opportunity to panel press). The onset of the siren during the second exposure did not result in a startle response, but did cause an orienting response in which the subject stopped engaging in appetitive activities and briefly looked in the direction of the siren, before continuing to eat from the food cup. Subject 276's behavior during the third exposure was similar to that for the second exposure: The onset of the siren produced a mild startle reaction followed by an orienting response; almost immediately thereafter, the subject resumed panel pressing and food consumption. Figure 28 shows the panel press rates for Subject 276 during each of the three exposures and for the time periods which immediately preceded each exposure.

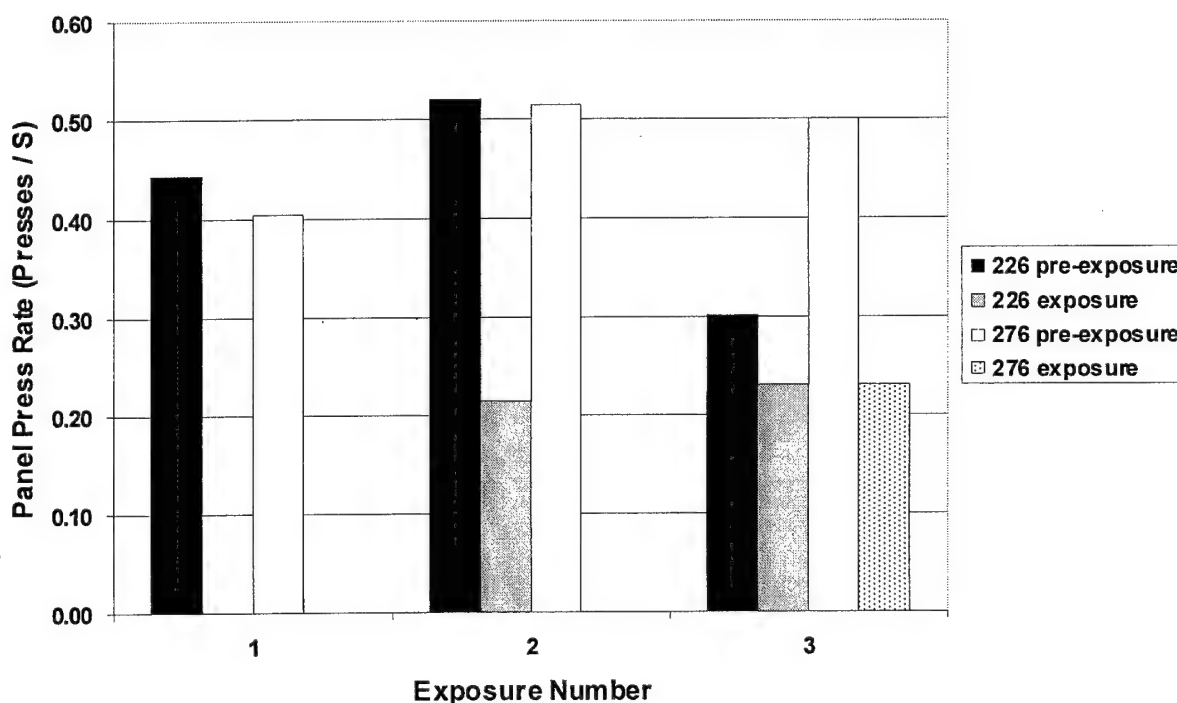


Figure 28. Panel-press rates prior to and during each of three exposures to the Dismounted Battlefield Battle Laboratory siren for Subjects 226 and 276. (Panel-press rates for 226 and 276 during Exposure 1 and for 276 during Exposure 2 were 0.00.)

In summary, the effects of the DBBL siren on the goal-directed behavior of the subjects were both minimal and transient. In only one instance was a subject driven away from the panel-press device and in that case it was for only a short distance; nor did this effect persist past that subject's first exposure. The siren onset often produced a startle and/or orienting response that persisted for some seconds, but for each subject the magnitude of the response habituated over the three exposures. (In all likelihood, the feature of the siren's acoustic output responsible for

subject startle responses was the initial pop as opposed to the lower-amplitude, sustained signal which followed.) In addition, panel-press rates were affected by the siren's output. In all cases, rates were lower during exposures than during the time periods that preceded them. However, the trend was for these rates to recover over the course of the exposures. For example, the panel-press rate for Subject 226 increased from 0.0 presses per s to 2.3 from the first to third exposure. Had subjects received additional exposures, it seems likely that exposure operant rates would eventually match those for non-exposure periods. Finally, consumption of the food available to subjects was only marginally affected by the DBBL siren; subjects failed to consume food during only one of the six exposures periods.

## SEQUENTIAL ARC DISCHARGE ACOUSTIC GENERATOR

### Experiment 1: Effect on Rhesus Monkeys Engaged in PEP Task

#### *Subjects*

Subjects were 3 adult male rhesus monkeys (*Macaca mulatta*) ranging in weight from approximately 7 to 11 kg. Subjects ranged in age from approximately 8 to 11 years at the time of testing. All rhesus subjects were housed and maintained as described in the *General Methods and Procedures* section. All subjects had been performing the PEP task on a regular basis for a minimum of 5 years.

#### *Apparatus*

*Acoustic Source.* The Sequential Arc Discharge Acoustic Generator (SADAG) was designed and built by the U. S. Army Research Laboratory. The SADAG produced high-intensity acoustic impulses by the sudden expansion of ionized gases produced when electrical discharges occur in air (Boesch et al., 2000). Figure 29 (modified after Boesch et al., 2000) shows a schematic of the SADAG. As depicted in this figure, the sequential discharges occurred between electrodes in an insulating tube, which was closed at one end and open at the other in order to direct the shock front caused by the discharges towards the target. Arc discharges caused a bright flash of light and, when discharged in air, the potential production of small amounts of ozone. Figure 30 shows the tripod-mounted SADAG in its experimental configuration with the beam director attached. The purpose of the beam director was to more narrowly focus the acoustic energy upon its intended target. The large box adjacent to the tripod housed the SADAG's discharging capacitors.

The timing of the SADAG discharges was adjustable; that is, they could be superimposed for a higher-amplitude discharge or spread out for a discharge of longer duration. It was also possible to vary the firing rate of the SADAG. It could be used in single-pulse or repetitive-pulse (burst) mode. In repetitive-pulse mode, pulses could be generated at a rate of up to 20 Hz. Prior testing with the device showed that when configured for maximal amplitude, the resulting acoustic waveform was very consistent, with a rise time for each pulse of approximately 20  $\mu$ s and a pulse width of approximately 200  $\mu$ s. Amplitude was typically measured at approximately 165 dB at 1 m over a 0.75-m-diameter footprint.

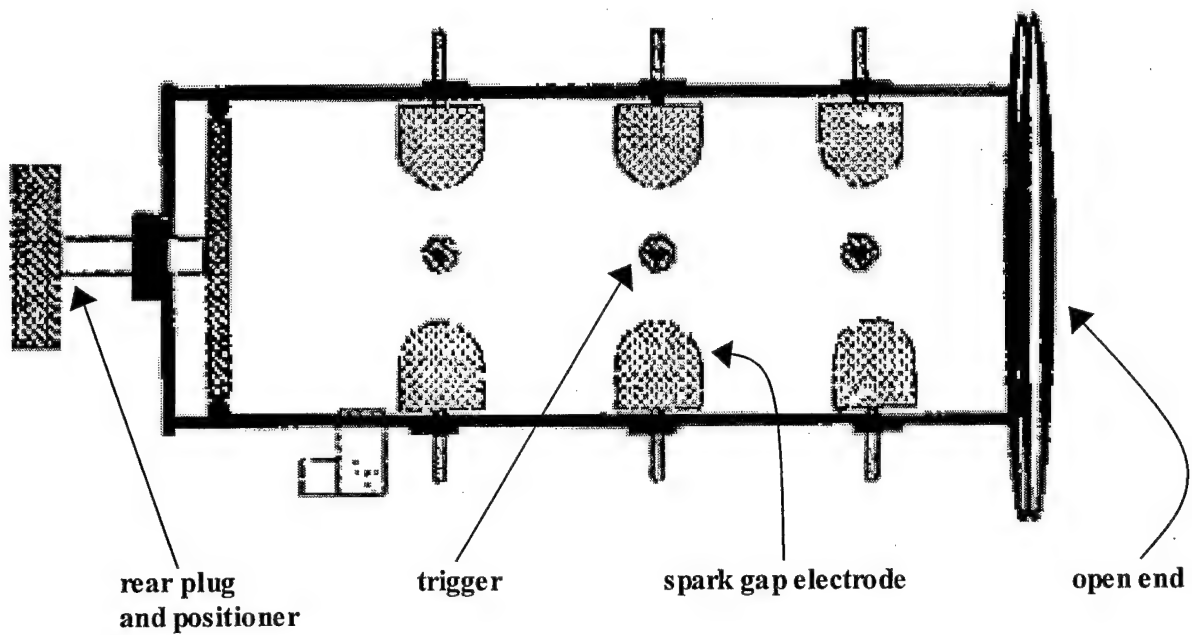


Figure 29. Schematic of the Sequential Arc Discharge Acoustic Generator.

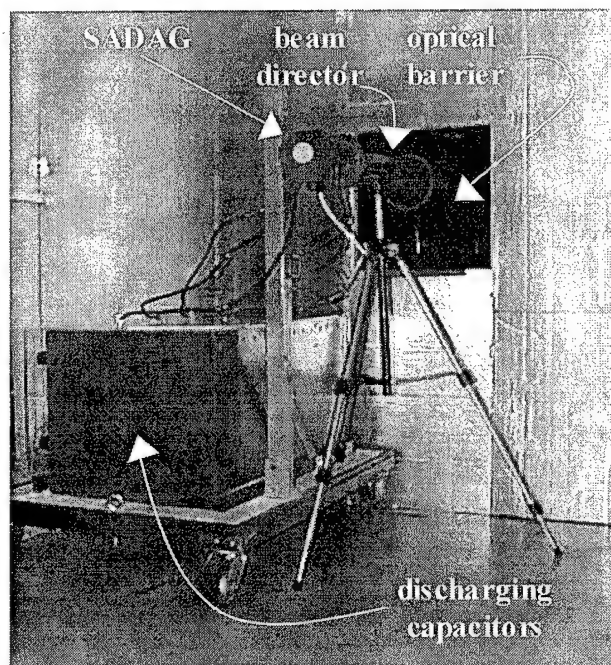


Figure 30. The Sequential Arc Discharge Acoustic Generator (with beam director) in its experimental setting.

*Acoustic Measurement.* The hardware and software typically employed in the measurement of acoustic signals (and described in the *General Methods and Procedures* section) were not specifically designed for the measurement of impulsive acoustic energy. Therefore, equipment belonging to ARL representatives present during testing was utilized to record acoustic signals.

*Equilibrium Platform.* All rhesus subjects were tested in the PEP. The task requirements for the PEP are described in the *General Methods and Procedures* section.

*Sound-Attenuating Chamber.* During all training and testing phases, the PEP was located inside of a 627.0 cm long x 284.0 cm wide x 200.0 cm high sound-attenuating chamber (Industrial Acoustics Company, Bronx, NY). During the testing phase, this sound-attenuating chamber was partitioned into two sections by 6.0-cm-thick dividing wall constructed of wood bracing and foam. The tripod-mounted SADAG and its peripherals were situated on one side of the dividing wall (271.0 cm long x 284.0 cm wide). The PEP, recording microphone, and video cameras were located on the opposite side of the wall (350.0 cm long x 284.0 cm wide). All remaining control and recording equipment were situated immediately outside of the sound-attenuating chamber. Figure 31 shows a schematic of the experimental setup. A square hole (approximately 50 cm x 50 cm) in the dividing wall allowed the acoustic energy emitted by the SADAG to impact upon the subject in the nearby PEP chair (see Figure 30). The square hole was covered by an "optical barrier" made from 2-mm-thick black, opaque plastic. The plastic allowed most of the acoustic energy to pass from one side of the chamber to the other but shielded the subject from the intense flash of light that accompanied discharge of the SADAG. Thus, any effect of the SADAG on subject behavior could more readily be attributed to the acoustic (as opposed to visual) properties of the device.

#### *Procedure and Data Analysis*

*Pre-Exposure PEP Training.* All 3 subjects received re-training on the PEP task during the months prior to being exposed to the siren. The five training sessions which immediately preceded the exposure PEP session were designated as the baseline PEP sessions. All baseline PEP sessions were 60 min in duration. For purposes of analysis, each 60-min baseline session was subdivided into 30 epochs of 2 min each. Shock frequency, mean chair position, and the standard deviation of chair position were calculated for each epoch as described in the *General Methods and Procedures* section.

*Pre-Exposure Hearing Tests and Earplug Insertion.* All subjects received two hearing batteries prior to being exposed to the SADAG. Each of the two sessions was comprised of the two individual tests discussed in the *General Methods and Procedures* section: (a) otoacoustic emissions, and (b) auditory brainstem response. The second of these two hearing batteries was conducted 40 to 60 days prior to being exposed to the SADAG.

For 1 of the 3 subjects, 914Z, an attempt was made to occlude the ear canals during the exposure. Approximately 5-6 hr prior to the PEP exposure session, the subject was anesthetized using propofol, and a foam earplug (E-A-RLink Foam Eartips, Cabot Safety Corporation, Indianapolis, IN) was inserted into each ear canal. Following earplug insertion, an additional

ABR was administered to the subject using the same procedure employed during the other pretest ABRs.

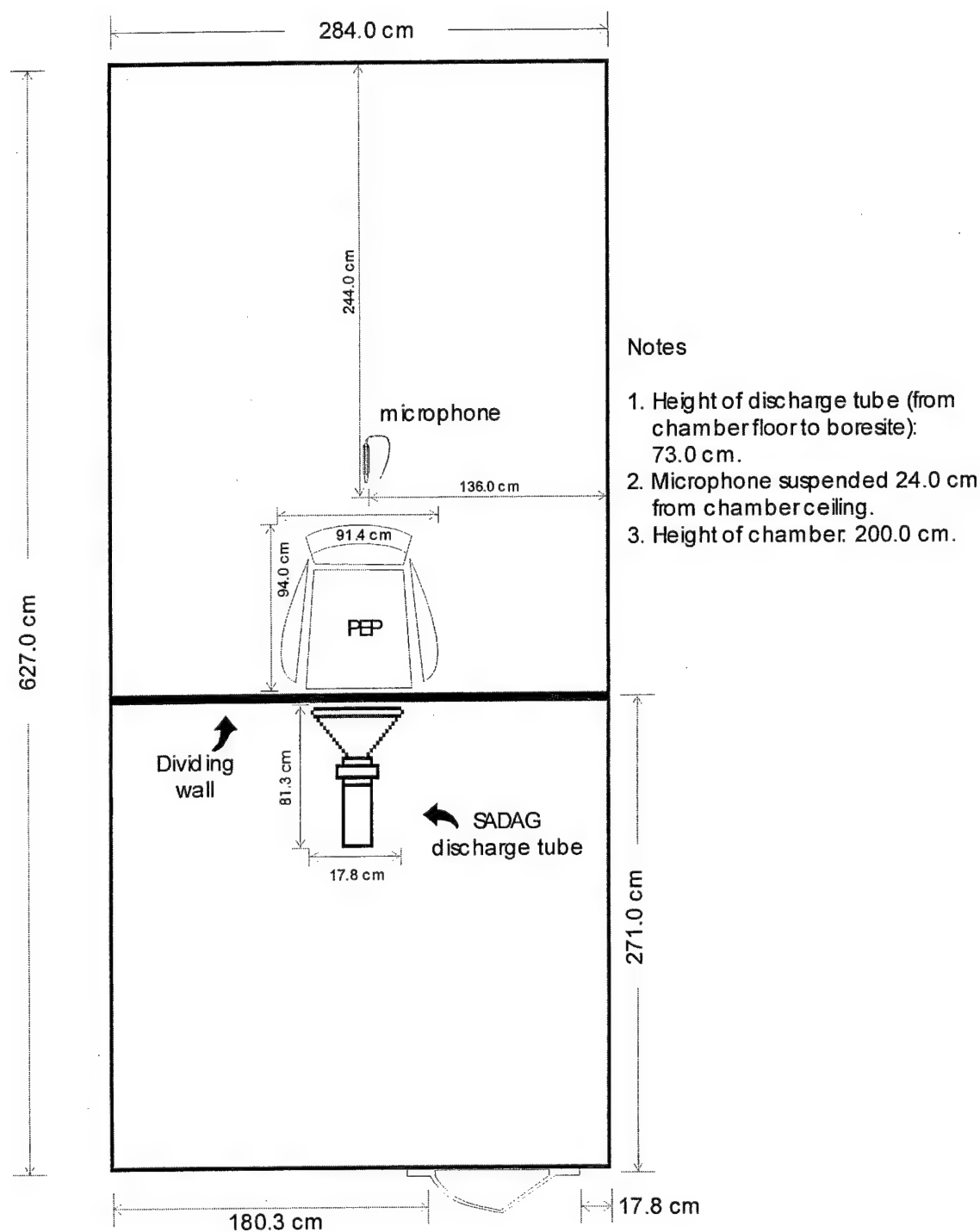


Figure 31. Experimental setup used with rhesus subjects during exposure to the Sequential Arc Discharge Acoustic Generator.



*Exposure to SADAG During PEP Task.* Each subject was exposed to the SADAG during a 60-min PEP session. During this exposure PEP session, shock frequency, mean chair position, and the standard deviation of chair position were calculated for each of the 30 2-min epochs (in a manner identical to their calculation during the baseline sessions). Further, chair standard deviation for each subject's exposure session was compared with chair standard deviation during the five baseline PEP sessions for that subject. More specifically, standard deviation values from the baseline sessions for a given subject were used to determine the range of normal performance for that subject by the method of simultaneous tolerance limits (see the *General Methods and Procedures* section for details). In addition, joystick position, chair position, forcing function, and shocks were digitally acquired using WINDAQ data acquisition software as described in the *General Methods and Procedures* section.

During the first 2-14 minutes of each exposure PEP session, subjects were allowed to perform the task as they did during a baseline session. Following this period, subjects were exposed one or more times to the SADAG. (The SADAG beam director was used for all exposures for each subject.) Exposure conditions varied for the 3 subjects: 510Z received five exposures. For two of the five exposures the SADAG delivered a series of single pulses; for the remaining three exposures the device was in repetitive-pulse (or burst) mode, delivering one or more bursts over a relatively short period of time. Both 642Z and 914Z received a single exposure of one or more bursts. Table 2 details the individual exposures for each of the 3 subjects.

Table 2. Exposure parameters for the 3 rhesus subjects in study utilizing the Sequential Arc Discharge Acoustic Generator.

Subject ID	Exposure Number	Description
570Z	1	24 single pulses; (each pulse at full amplitude); duration (first pulse to last) of 148.4 s; mean rate of 0.16 pulses/s
	2	13 single pulses; (each pulse at full amplitude); duration (first pulse to last) of 47.2 s; mean rate of 0.28 pulses/s
	3	5 bursts of 2.9 s each (each burst at full amplitude); pulse rate for each burst of 10.3 Hz; total duration (beginning of first burst to end of last) of 130.0 s
	4	1 burst of 9.8 s (at full amplitude); pulse rate for burst of 10.1 Hz
	5	3 bursts of 2.95 s each (each burst at full amplitude); pulse rate for each burst of 20.3 Hz; total duration (beginning of first burst to end of last) of 42.0 s
642Z	1	1 burst of 29.8 s (at $\frac{3}{4}$ amplitude); pulse rate for burst of 10.0 Hz
914Z	1	approximately 20 bursts of (each burst at $\frac{3}{4}$ amplitude); pulse rate for each burst of approximately 10 Hz; problems with Army Research Laboratory equipment precluded more precise (or additional) measurements

*Post-Exposure Hearing Tests.* All subjects received a hearing battery following their PEP exposure session. This post-exposure hearing battery followed exposure by less than 1 hour. Each post-exposure hearing battery was comprised of the same two individual tests employed in the pre-exposure batteries. One subject, 642Z, received five additional post-exposure hearing batteries. The first three followed exposure by approximately 1, 2, and 4 weeks; the last two followed by approximately 2 and 4 months.

### *Results and Discussion*

*PEP Task and Acoustic Measurements.* Acoustic measurements during each of the exposures for the 3 subjects were made by ARL technical personnel. Although data for all of the exposures are not available, ARL recording equipment indicated that the SADAG performed as expected. Figure 32 depicts a single-pulse pressure waveform generated by the SADAG during either Exposure 1 or Exposure 2 for 570Z. The equivalent sound pressure level of the waveform at the subject location was determined to be approximately 165 dB.

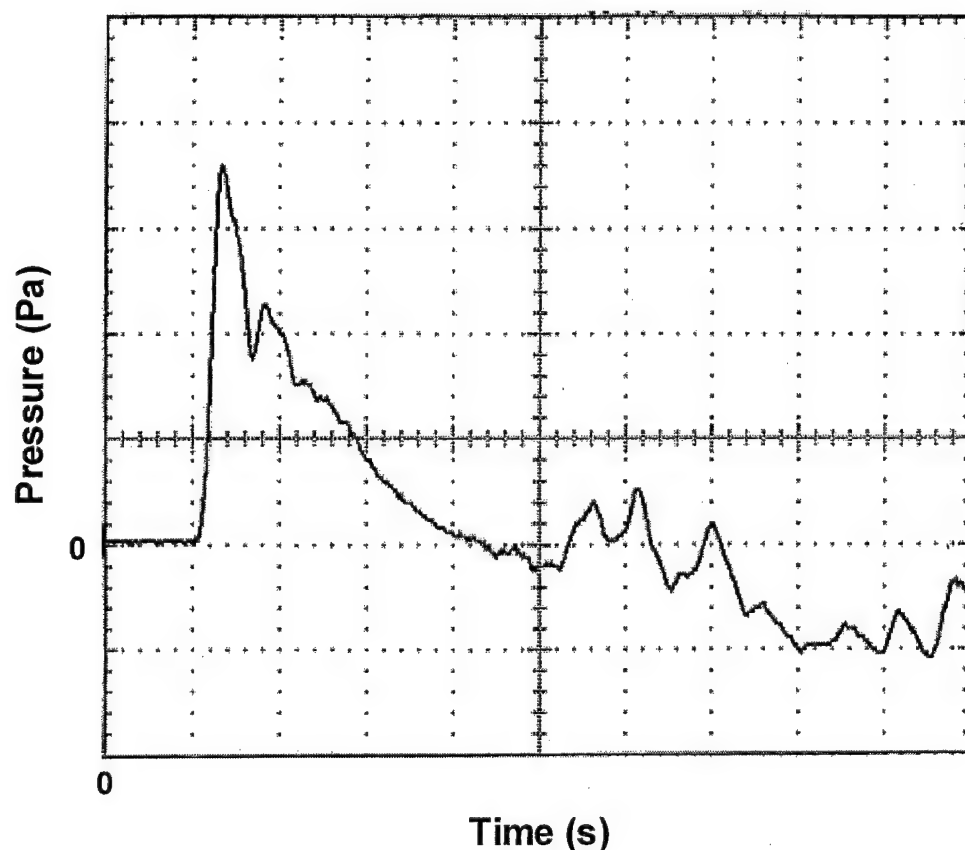


Figure 32. Representative pulse emitted by the Sequential Arc Discharge Acoustic Generator during exposure of Subject 570Z. (Grid lines for the x-axis are in increments of 50  $\mu$ s. Grid lines for the y-axis are in increments of 1 kPa.)

Figures 33, 34, and 35 depict the PEP performances of Subjects 570Z, 642Z, and 914Z, respectively. In overview, exposure to the SADAG did not alter PEP performance in a statistically significant manner for either 570Z or 642Z. That is, for neither of these 2 subjects did the standard deviation for platform (chair) position exceed the calculated 99% confidence limit during any of the test epochs during which the SADAG was on. Further, neither 570Z nor 642Z received any shocks over the course of their PEP exposure sessions. Figure 34 does show a statistically significant decrement in PEP performance for 642Z, but this occurred during Epoch 29 of the 30-epoch exposure session, whereas the single SADAG exposure for this subject occurred during Epoch 8. Thus, although it is unclear what accounted for the high chair standard deviation during Epoch 29, it was almost certainly not the result of the SADAG.

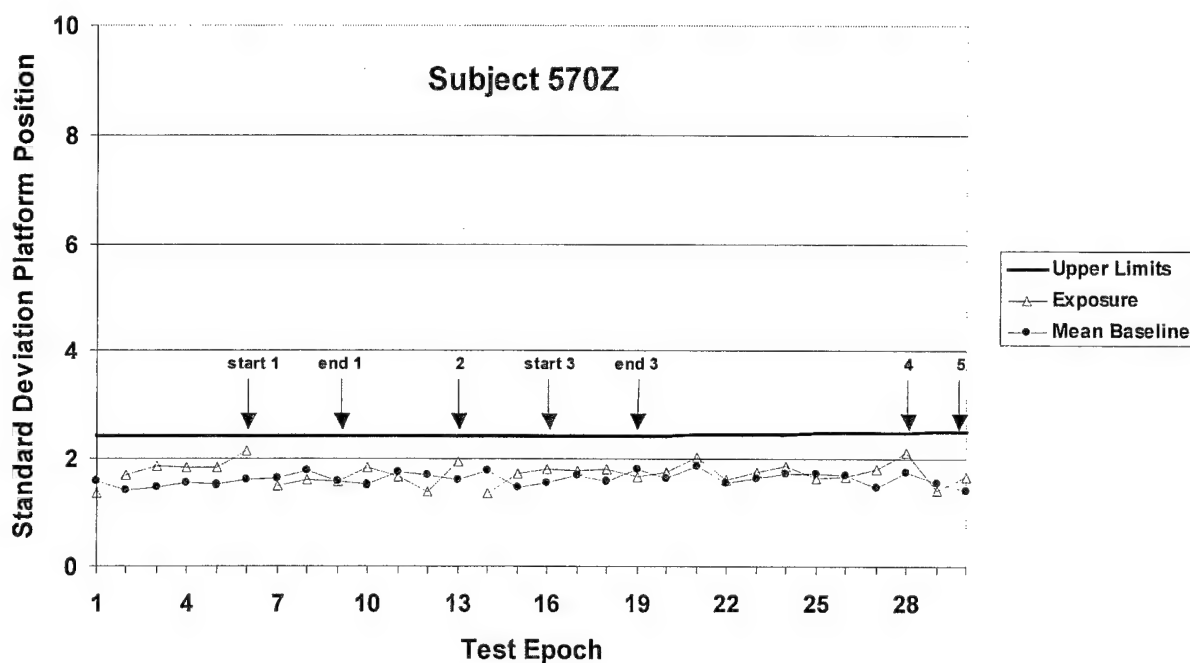


Figure 33. PEP performance of 570Z during exposure to the Sequential Arc Discharge Acoustic Generator (SADAG). (Arrows indicate epochs during which SADAG was on.)

Interpretation of the PEP data for 914Z is extremely problematic. As noted, this subject was treated prior to the exposure session: The ear canals were occluded with foam plugs, followed by the administration of the standard ABR test. This was done in an attempt to limit the acoustic energy impinging upon the subject's eardrums and hence assess any possible extra-aural effects of the SADAG on subject behavior. Unfortunately, the plug inserted in the right ear was dislodged either before or during the single SADAG exposure, making such assessments impossible. In addition, because these pre-exposure procedures were performed under the influence of an anesthetic (propofol), an attempt was made to allow sufficient time to pass before starting the PEP exposure session in order that measurements remain uncontaminated by effects of the anesthetic. Unfortunately, although veterinary personnel agreed that sufficient time had

elapsed (approximately 3 hr), initial data from the PEP task (as reflected in Figure 35) show that

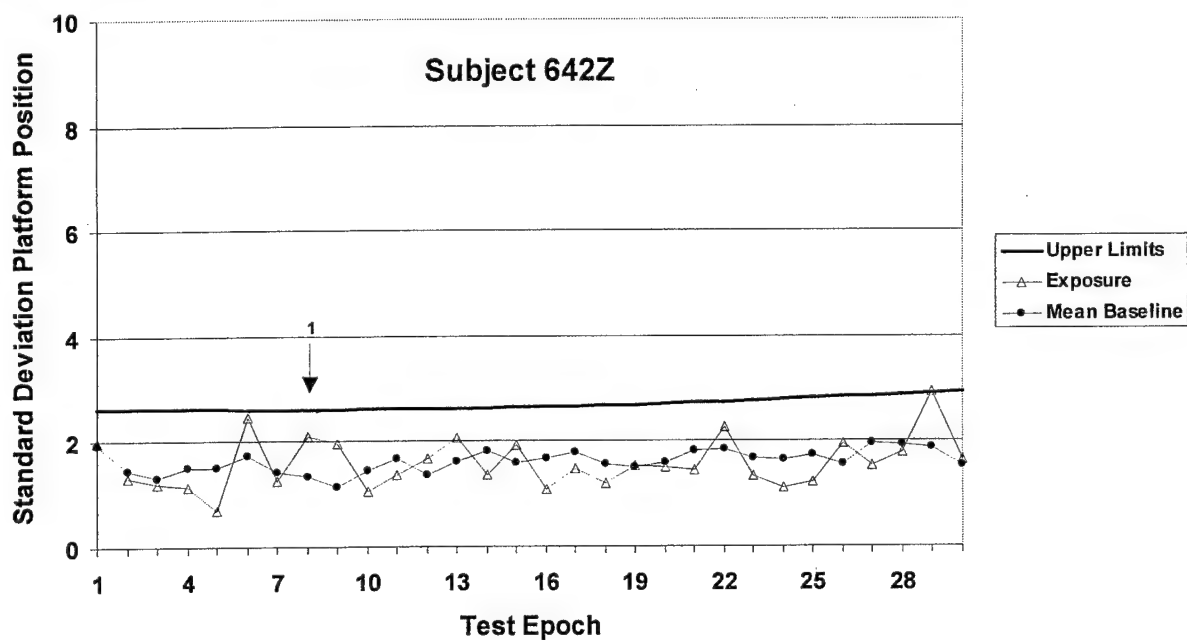


Figure 34. PEP performance of 642Z during exposure to the Sequential Arc Discharge Acoustic Generator (SADAG). (Arrow indicates epoch during which SADAG was on.)

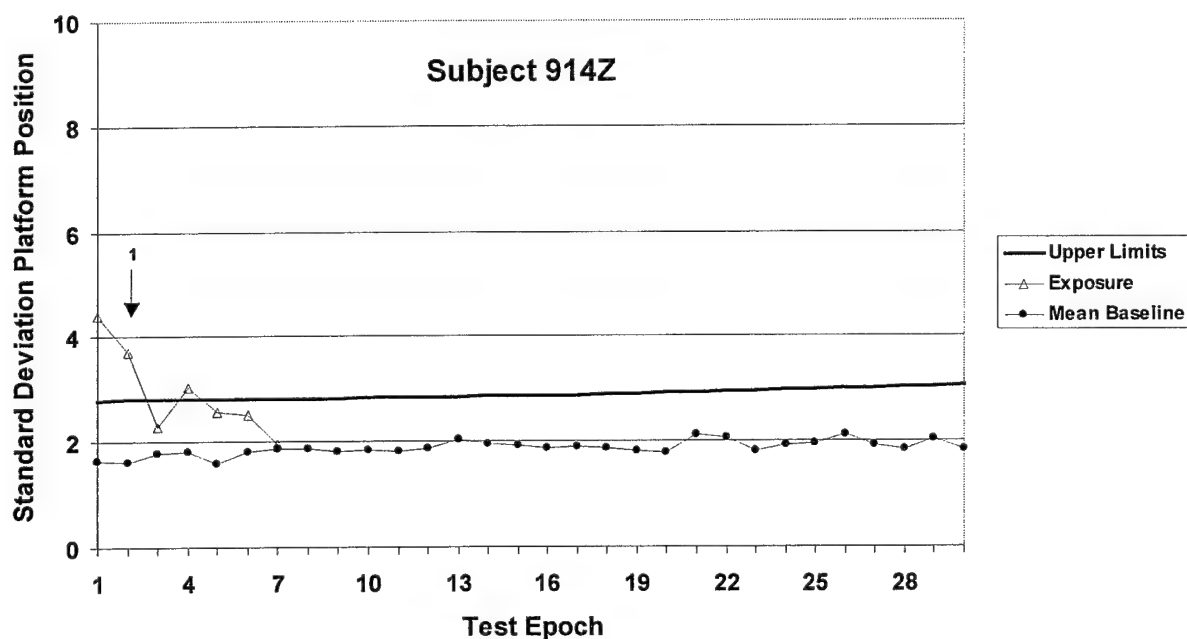


Figure 35. PEP performance of 914Z during exposure to the Sequential Arc Discharge Acoustic Generator (SADAG). (Arrow indicates epoch during which SADAG was on.)

this was almost certainly not the case. Specifically, the platform standard deviation for Epoch 1 is well above the 99% confidence limit ( $SD = 4.41$ ). Hence, the fact that platform standard deviation for Epoch 2 (during the SADAG exposure) also exceeds the confidence limit ( $SD = 3.70$ ) does not unambiguously support the hypothesis that any performance decrement resulted from the exposure (as opposed to the aftereffects of the anesthetic or to some combination of factors including the aftereffects of the anesthetic). These problems led Subject 914Z to be removed from the PEP following only 7 of the scheduled 30 epochs.

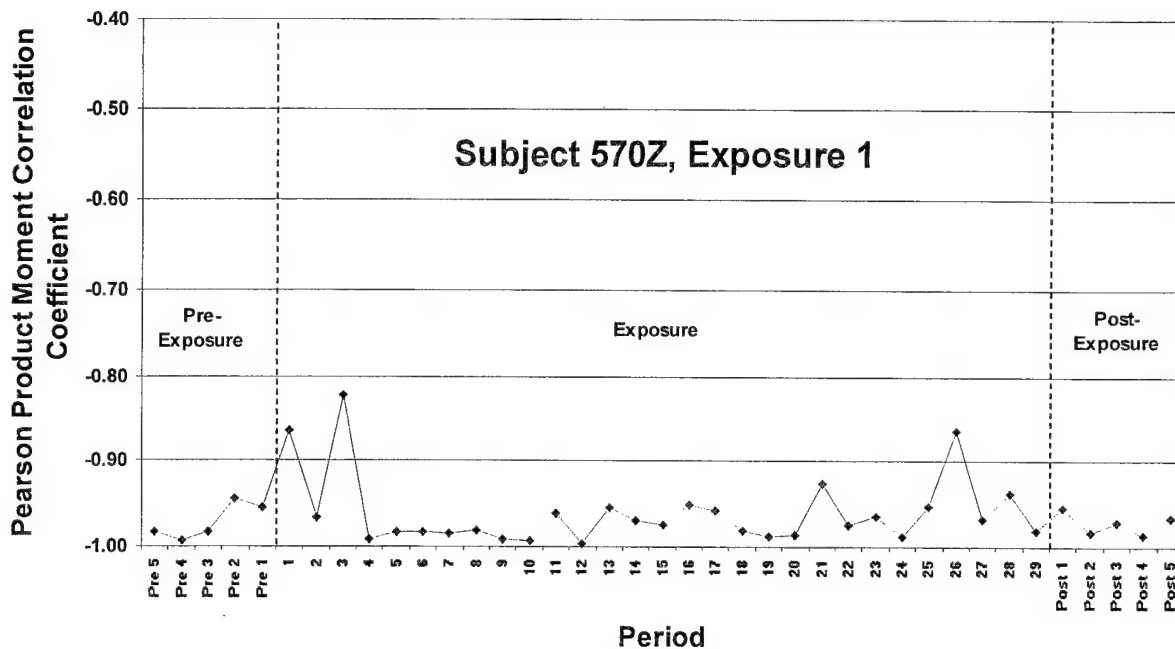


Figure 36. Pearson product moment correlation coefficients between joystick position and forcing function before, during, and following Exposure 1 of Subject 570Z to Sequential Arc Discharge Acoustic Generator. (For all  $r$ 's,  $p < .01$ .)

Although the foregoing results failed to uncover any statistically significant degradation in PEP performance resulting from exposure to the SADAG, an examination of data collected with the WINDAQ hardware and software reveals a pattern of more subtle effects. (Such data were only available for Subjects 570Z and 642Z. ARL equipment problems precluded a meaningful examination of WINDAQ data for 914Z.) Figures 36-41 show the sequence of Pearson product moment correlation coefficients between forcing function and joystick position over periods ranging from before to after each of the SADAG exposures for 570Z and 642Z. (See *Results and Discussion* of data from the CADS study for discussion concerning the expected relationship between these two variables.) Figures 36 and 37 detail correlation coefficients corresponding to the two single-pulse exposures (Exposures 1 and 2 for Subject 570Z, respectively; see also Table 2). Coefficients in these two figures are based on a number of data points equivalent to a 5-s duration. In the case of Exposure 1, pre-exposure values are all less than  $-0.90$  (indicative of relatively stable performance). In contrast, during the exposure, coefficients for 3 of the 29 5-s intervals exceed  $-0.90$ , specifically for the first, third, and twenty-sixth intervals. Any tendency

towards “erratic” performance is absent during each of the intervals following the exposure,  $r$ 's  $\leq$  -.95. In addition, “erratic” performance remains absent during the entirety of Exposure 2: None of the coefficients — including those for the nine 5-s intervals comprising the exposure — exceed -.90 ( $r$ 's  $\leq$  -.91).

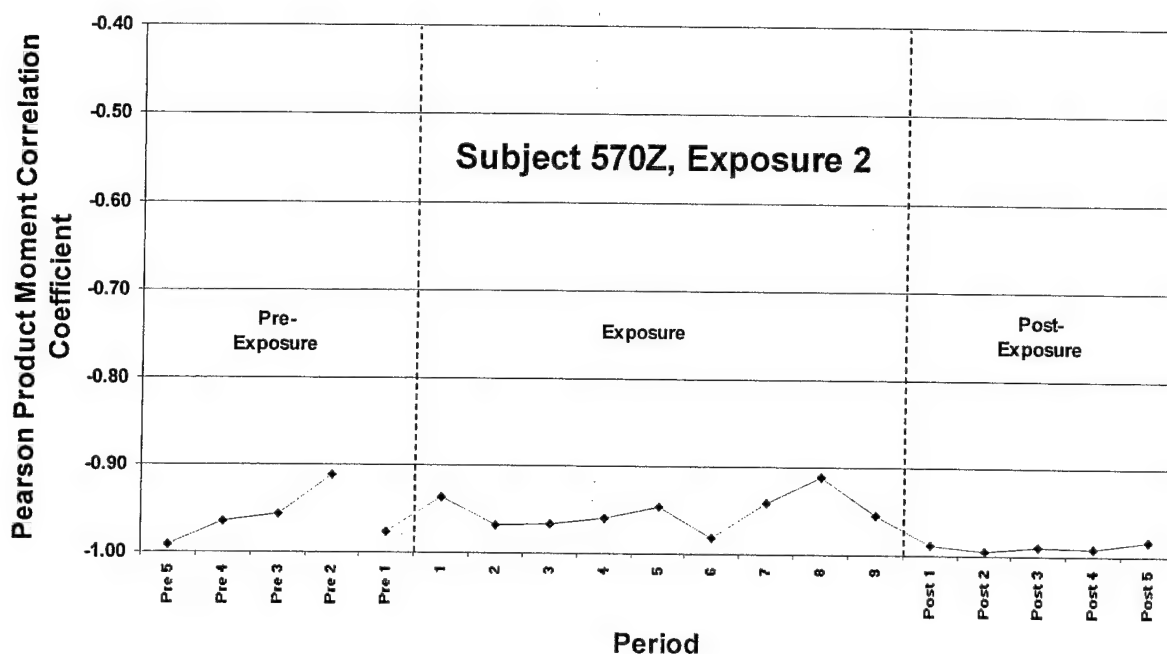


Figure 37. Pearson product moment correlation coefficients between joystick position and forcing function before, during, and following Exposure 2 of Subject 570Z to Sequential Arc Discharge Acoustic Generator. (For all  $r$ 's,  $p < .01$ .)

Figures 38-40 show correlation coefficients for the three burst-mode exposures for Subject 570Z. The individual bursts comprising Exposures 3 and 5 (Figure 38 and 40) were 2.9 and 2.95 s in duration, respectively (see Table 2). Therefore, each correlation coefficient for those exposures corresponds to a 2.9-s (or 2.95-s) period of time. In contrast, Exposure 4 consisted of a much longer single burst of approximately 10 s. For purposes of the correlational analysis, the 10-s exposure period was subdivided in two and each coefficient was based on approximately 5 s of data (see Table 2 and Figure 39). A consequence of the shorter computational intervals for Exposures 3 and 5 is that any erratic performance of a given fixed duration will have a relatively greater impact on the correlation; thus, comparison of values derived for Exposures 3 and 5 with those for the remaining exposures may be ill-advised.<sup>2</sup> The figures for both Exposures 3 and 5

<sup>2</sup> As a corollary to this caveat, it should be noted that occasionally the PEP forcing function is relatively “flat” for very brief periods. That is, during these periods the forcing functioning is not to any significant degree altering platform position. However, even during such periods, rhesus subjects show an overwhelming tendency to continue to make minute adjustments to the joystick position. In cases where such a “flat” interval coincides with all or most of a short calculation interval, coefficients with spuriously low absolute values often result. In an effort to avoid interpretational difficulties, coefficients were not calculated for intervals where the standard deviation for the forcing function was less than or equal to 0.08. (A standard deviation of 0.08 represents approximately 11% of the maximum possible variability.)



show relatively substantial deviations from optimal PEP performance. Coefficients exceed  $-.80$  during Bursts 2 and 3 of Exposure 3 ( $r$ 's =  $-.58$  and  $-.64$ , respectively). The correlation coefficient for the first interval following Burst 3 also exceeds  $-.80$ ,  $r = -.71$ . Similarly, coefficients for all three bursts comprising Exposure 5 exceed  $-.80$  (viz.,  $r$ 's  $\geq -.75$ ). Finally, correlation coefficients for the two 5-s intervals corresponding to the Exposure 4 burst exceed  $-.90$ . In contrast, coefficients for intervals both preceding and following all three burst exposures indicate more or less stable performance.

Figure 41 shows the joystick-forcing function correlation coefficients for the single burst-mode SADAG exposure (approximately 30 s in duration, analyzed in 5-s segments) for 642Z. The pattern of results indicate stable PEP performance prior to the exposure ( $r$ 's  $> -.96$ ), a departure from stable flying during the first 5-s interval of the exposure ( $r = -.73$ ), followed by a return to relatively stable performance for the remainder of the exposure ( $r$ 's  $\geq -.95$ ).

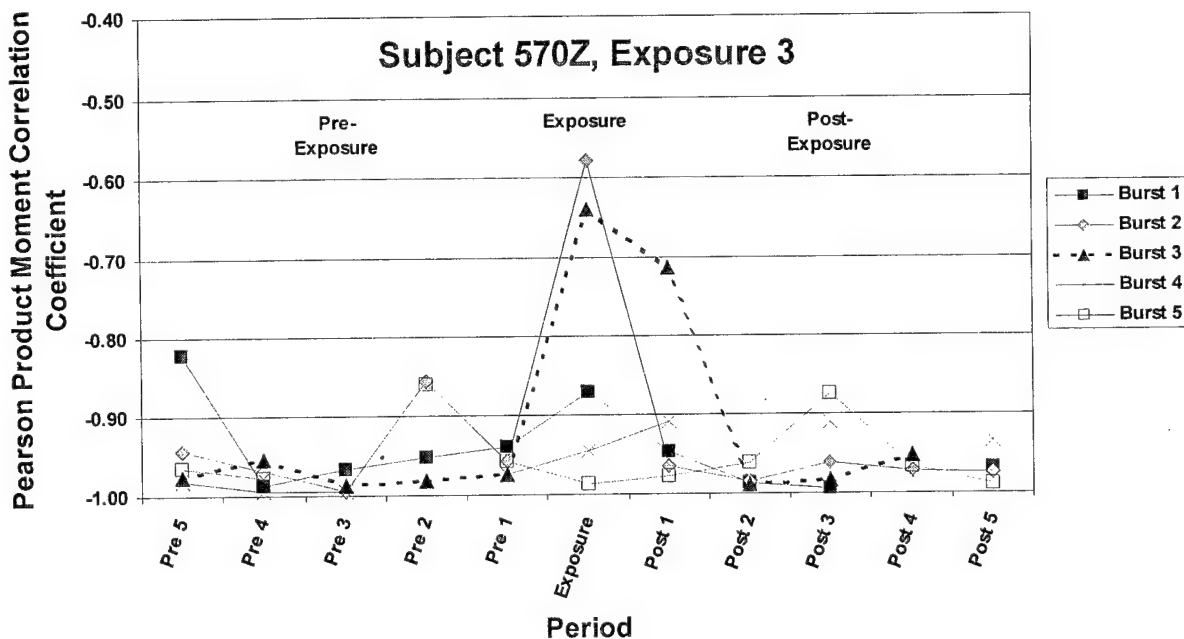


Figure 38. Pearson product moment correlation coefficients between joystick position and forcing function before, during, and following five bursts comprising Exposure 3 of Subject 570Z to Sequential Arc Discharge Acoustic Generator. (For all  $r$ 's,  $p < .01$ .)

*Hearing Tests.* Exposure to the SADAG had a measurable impact on the hearing of all 3 subjects. Further, as inferred by data for Subject 642Z, who was tested at irregular intervals out to approximately 6 months following exposure, this deficit was a long-term one.

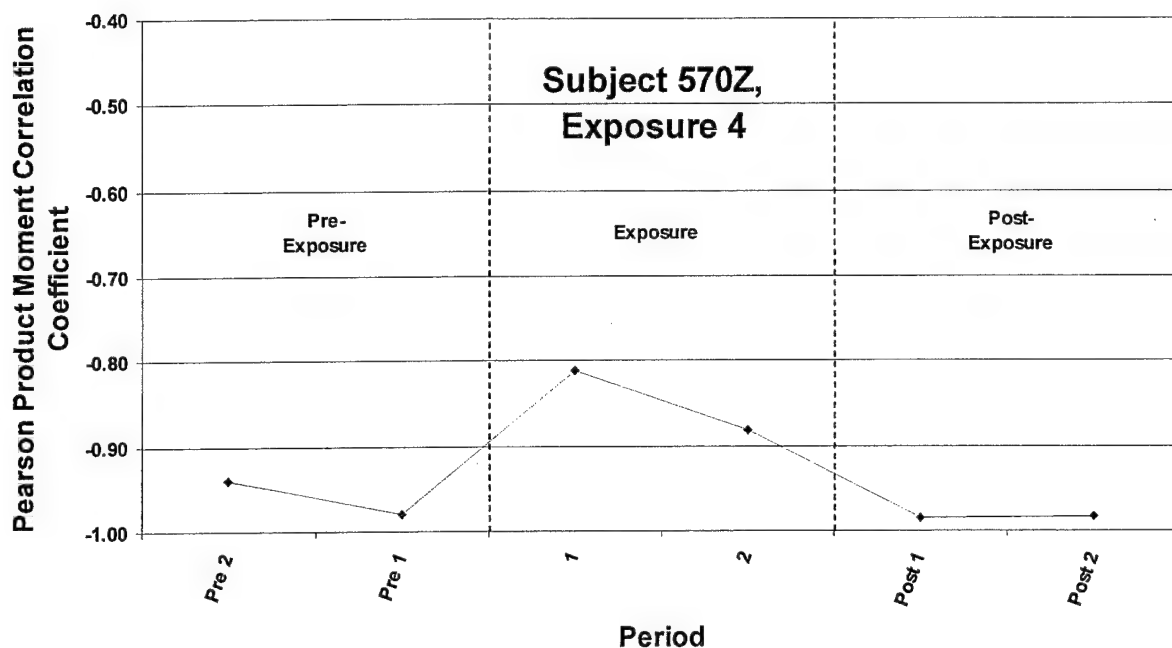


Figure 39. Pearson product moment correlation coefficients between joystick position and forcing function before, during, and following Exposure 4 of Subject 570Z to Sequential Arc Discharge Acoustic Generator. (For all  $r$ 's,  $p < .01$ .)

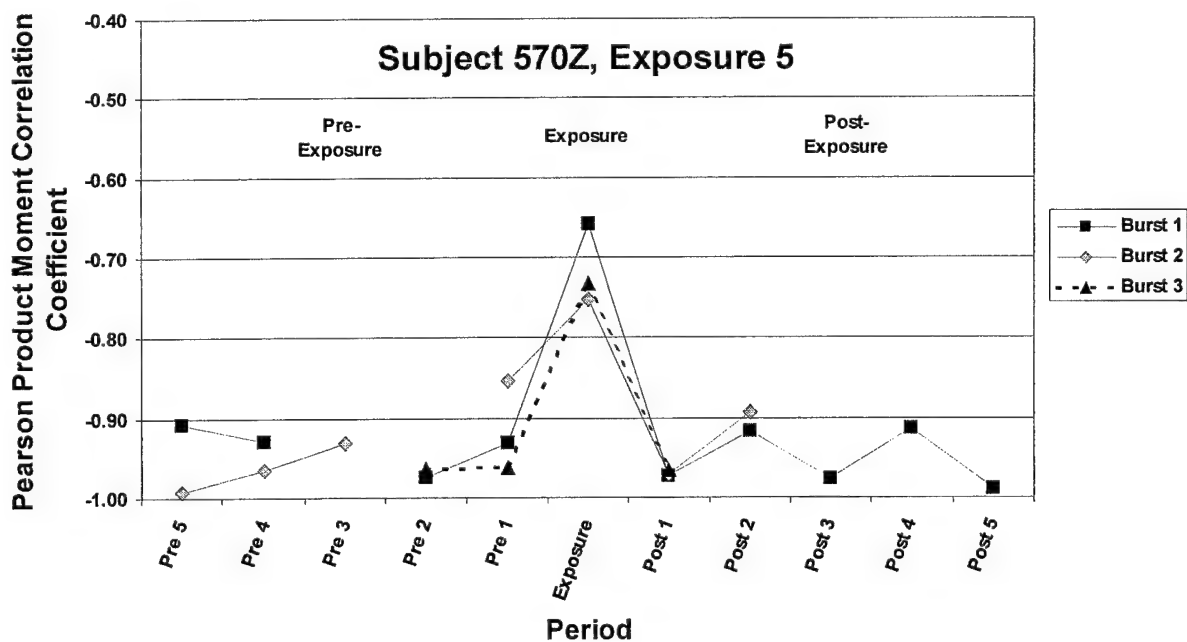


Figure 40. Pearson product moment correlation coefficients between joystick position and forcing function before, during, and following three bursts comprising Exposure 5 of Subject 570Z to Sequential Arc Discharge Acoustic Generator. (For all  $r$ 's,  $p < .01$ .)

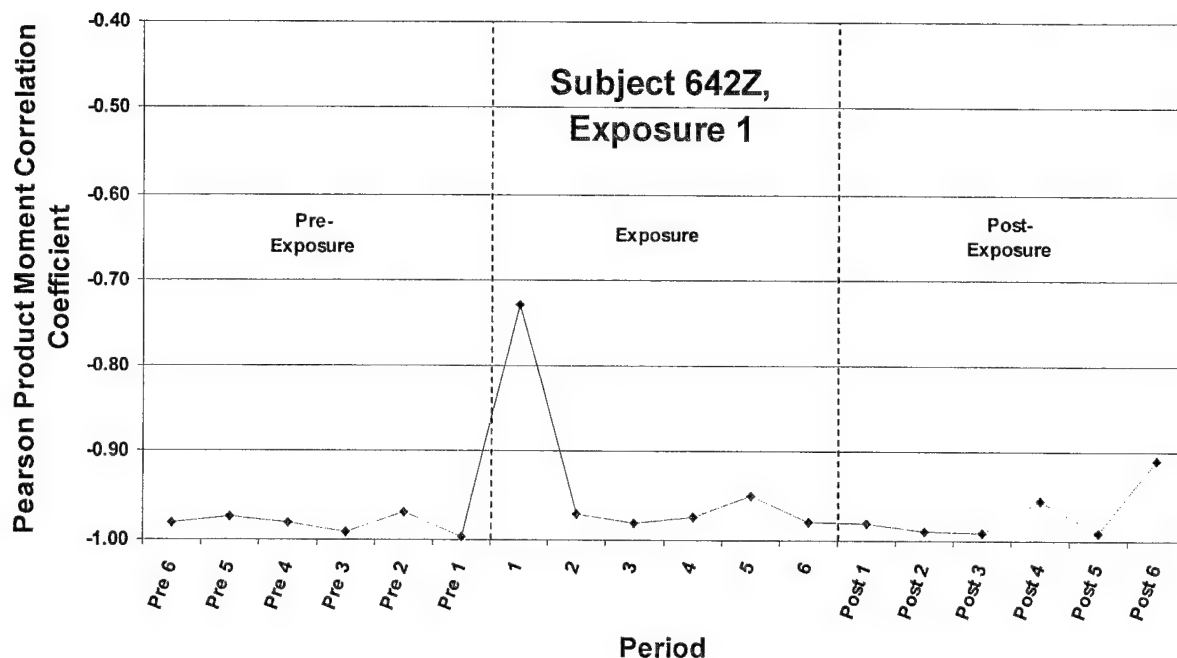


Figure 41. Pearson product moment correlation coefficients between joystick position and forcing function before, during, and following Exposure 1 of Subject 642Z to Sequential Arc Discharge Acoustic Generator. (For all  $r$ 's,  $p < .01$ .)

ABRs conducted prior to exposure indicated normal peripheral sensitivity for all 3 subjects. For all subjects, click stimuli produced replicable responses down to 10 dBnHL in both the right and left ear. Tones bursts at 500 Hz produced replicable responses ranging from 20-50 dBnHL bilaterally; tones bursts at 4 kHz also produced replicable responses ranging from 20-50 dBnHL bilaterally. Table 3 summarizes the pre-exposure ABR data for the 3 subjects.

As previously noted, for 1 of the 3 subjects, 914Z, an attempt was made to occlude the ear canals during the exposure by insertion of foam earplugs. Comparative ABR tests (conducted approximately 5-6 hr prior to exposure) that measured sensitivity both with and without the earplugs, indicated that their insertion in the ear canal resulted in a threshold deficit of approximately 20 dB in each ear. Unfortunately, either prior to or during the single exposure experienced by 914Z, the earplug in the right ear was dislodged.

ABR tests conducted in the immediate aftermath of exposure to the SADAG produced no replicable responses at all either 570Z or 642Z. (The highest amplitude signal employed in the ABR procedure was 80 dB.) In the case of Subject 914Z, responses for the left ear (occluded with earplug) were identical to those recorded during the pre-exposure test. In contrast, there were no replicable responses for the right (non-occluded) ear. Further tests with Subject 642Z indicated that the deficit was not permanent, but was slow to recover and that even 6 months after exposure, peripheral sensitivity had not returned to normal levels. Post-exposure ABR data for the 3 subjects is summarized in Table 3.

Table 3. Estimated thresholds of auditory brainstem responses for 3 rhesus subjects prior to (Pre), immediately following (Post), and 6 months after exposure to Sequential Arc Discharge Acoustic Generator. (Data at 6 months only available for Subject 642Z.)

Stimulus	Ear	Subject ID						
		570Z		642Z			914Z	
		Pre	Post	Pre	Post	6-Month	Pre	Post
Click	right	10	>80	10	>80	50	10	>80
	left	10	>80	10	>80	60	10	10
500-Hz Tone	right	20	>80	20	>80	50	50	>80
	left	20	>80	20	>80	60	50	50
4-kHz Tone	right	30	>80	40	>80	60	40	>80
	left	20	>80	20	>80	60	50	50

DPOAE amplitudes for all subjects prior to exposure to the SADAG indicated normal cochlear function. In contrast, DPOAE testing conducted immediately after exposures revealed no measurable emissions for either the right or left ears for both 570Z and 642Z. Post-exposure results for Subject 914Z paralleled that subject's ABR data: that is, responses for the left (occluded) ear were comparable to pre-exposure results, whereas responses for the right (occluded) ear were identical to 570Z and 642Z. Additional follow-up tests administered to 642Z indicated that any recovery of function over time was very slight. Figure 42 summarizes the DPOAE data for one ear (left) for Subject 642Z. In summary, exposure to the SADAG produced measurable and pronounced short- and long-term hearing deficits in subjects exposed to its signal for a period of time as brief as 30 s (Subject 642Z). Whether these deficits are permanent or not would require a longer-term longitudinal assessment of hearing impairment following exposure.

Interpretation of SADAG effects on PEP performance is less straightforward. Short-term effects of the SADAG on PEP performance were evident. Digitized data from the subject joystick and the system forcing function showed a pattern in which PEP performance tended to be momentarily disrupted coincident with onset of the SADAG. In other words, subjects tended to be somewhat less accurate in compensating for changes in chair position with the PEP joystick. This "startle-like" effect was, as noted, of brief duration. Thus, normal performance typically returned immediately after the offset of brief 10- and 20-Hz bursts (Exposures 3 and 5, respectively, for Subject 570Z; see Figures 38 and 40). Moreover, in the case of longer exposures (either single-pulse or burst mode), performance decrements did not persist throughout the entire exposure period; instead stable flying typically re-emerged prior to SADAG offset. This occurred during 570Z's first exposure (single-pulse mode), where — with the exception of a single 5-s interval late in the 148-s exposure — stable flying returned after the first 15 s of the exposure (see Figure 36). Similarly, stable PEP performance reappeared after the first 5 s of the 30-s burst-mode exposure experienced by 642Z (see Figure 41).

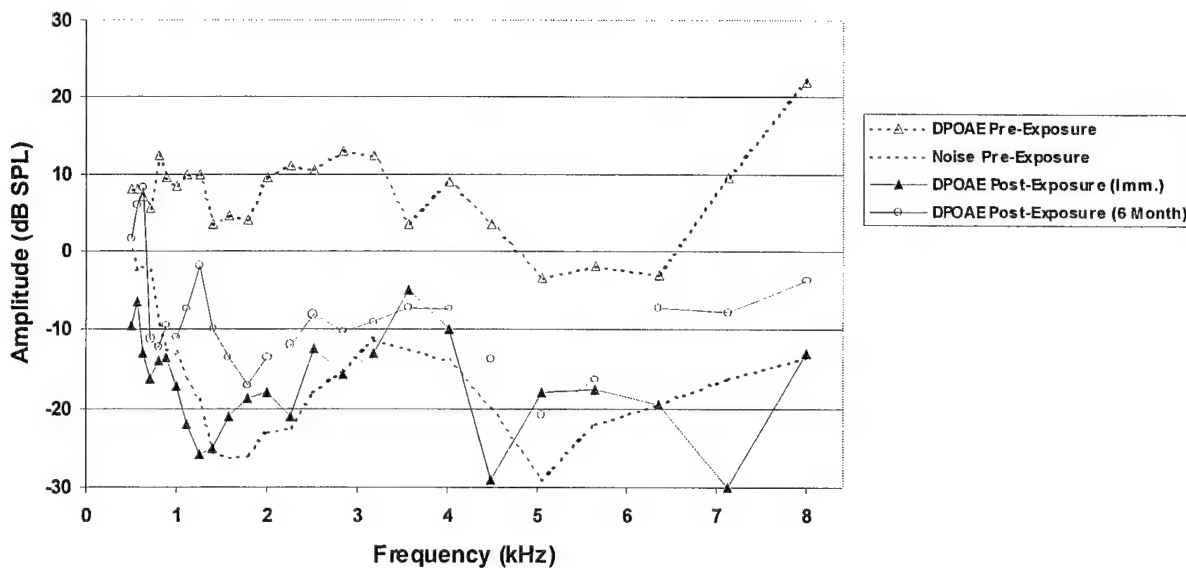


Figure 42. Amplitude of distortion product otoacoustic emissions (DPOAE) prior to, immediately after (Imm.), and 6 months after exposure to the Sequential Arc Discharge Acoustic Generator for the left ear of Subject 642Z. (Noise floor shown only for pre-exposure testing session.)

It should also be noted that while these effects were of relatively brief duration, they did not appear to habituate to any great degree over the short course of the study. The data from 570Z, who received five exposures over a period of about 20 min, is relevant: The startle-like effects, as reflected by the correlational analyses, that were apparent during Exposure 1 did, in fact, disappear during the entirety of Exposure 2. But they re-emerged to a greater or lesser degree during each of Exposures 3, 4, and 5. This failure to habituate is somewhat puzzling given that hearing data from Subjects 642Z and 914Z would seem to indicate that hearing deficits occurred almost immediately. Thus, the persistence of startle-like effects in PEP tracking may be a consequence of extra-aural factors (light emitted by the device possibly penetrating the optical barrier, ozone emission, etc.). Alternatively, it may be that even with pronounced hearing deficits, the effective amplitude of the SADAG was sufficient to produce these momentary PEP performance deficits.

However, in perhaps the most important sense, exposure to the SADAG clearly failed to impact PEP performance: The subject's goal during the task is to keep the device platform within the prescribed pitch limits ( $\pm 15^\circ$ ) in order to avoid negative reinforcement (shock). Clearly, PEP data for the 2 relevant subjects — 570Z and 642Z — indicate that they were successful. Neither subject received a single shock during the course of any SADAG exposure.

## Experiment 2: Effect on Swine Engaged in Panel-Pressing Task

*Subjects.* Subjects were 2 male minipigs (*Sus scrofa*). Both subjects were procured, housed, and maintained as described in the *General Methods and Procedures* section. At the time of testing subjects were between 1 and 2 years of age and weighed approximately 80-90 kg.

### *Apparatus*

*Acoustic Sources and Measurement.* The same Sequential Arc Discharge Acoustic Generator (SADAG) described in the preceding experiment involving rhesus subjects was employed in the present study. All design specifications and performance parameters were identical. As in the previous study involving the SADAG, equipment belonging to ARL personnel present during testing was utilized to record acoustic signals.

*Panel-Pressing Equipment.* A panel-press device, designed by Whitmore Enterprises (San Antonio, TX) for use by swine and described in detail in the *General Methods and Procedures* section, was employed. Delivery of the food and recording of the panel-press responses were further controlled by various Coulbourn modules (Coulbourn Instruments, Allentown, PA) also described in detail in the *General Methods and Procedures* section.

*Sound-Attenuating Chamber.* During all training and testing phases, the panel-pressing device and associated control equipment were located inside of a 627.0 cm long x 284.0 cm wide x 200.0 cm high sound-attenuating chamber (Industrial Acoustics Company, Bronx, NY). The panel-pressing apparatus was mounted on a wood 183.0 cm wide x 183.0 cm long x 46.0 cm high platform (hereafter referred to as the asset platform). A 62.0 cm wide x 112.0 cm moveable wood ramp allowed subjects to gain access to the asset platform and panel-press device. Figure 43 illustrates the position of panel-press apparatus on the asset platform.

During the testing and exposure phases, the tripod-mounted SADAG was positioned so that it faced the panel-press device; specifically the open end of the discharge tube was 84.0 cm from the panel-press device's food cup. During the exposure phase a Brüel & Kjær microphone, used by ARL in recording the acoustic output of the SADAG, was suspended over the approximate position of the food cup at a height of 91.5 cm above the platform floor (see Figure 43). An optical barrier, composed of a sheet of black, opaque plastic, separated the SADAG from the platform. The purpose of this barrier, as with the rhesus study, was to allow penetration of the acoustic energy from one side of barrier to the other, but shielding the subject from the intense flash of light that accompanied discharge of the SADAG. A number of high-intensity lamps were set in the chamber to increase the ambient light intensity and hence decrease the relative magnitude of the light emitted by the SADAG.<sup>3</sup> Figure 44 shows one of the assets on the

<sup>3</sup> On Day 1 of testing, different optical barriers were used for the 2 subjects. In the case of the first subject run, 544, a smaller version of the barrier — measuring approximately 1 m wide x 1 m high x 1 mm thick — was employed. Observers, however, subsequently judged that the size of this barrier was insufficient in shielding the subject from the light flash that coincided with the SADAG's discharge. Thus, for the second subject run on Day 1, 538, a much larger barrier was erected, measuring 1.61 m long x 2.0 m high x 2 mm thick, and extending from the floor to the ceiling of the chamber. (The thickness of the second barrier was somewhat less — approximately 1 mm — in a small section where it was directly opposite the end of the discharge tube.)



platform with immediately prior to the test session. (The optical barrier has not yet been set in place.)

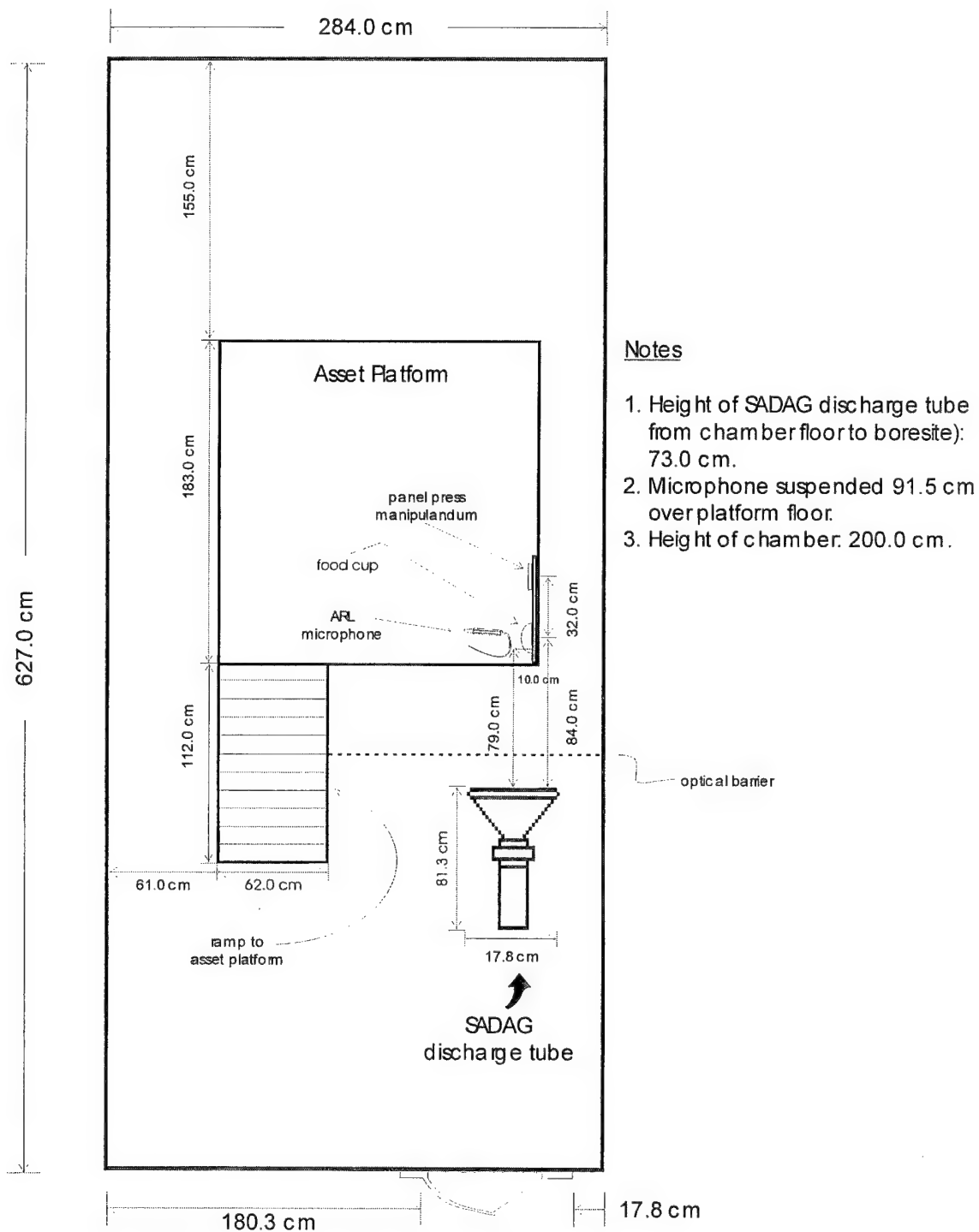


Figure 43. Experimental setup used with two minipigs during exposure to the Sequential Arc Discharge Acoustic Generator (SADAG).

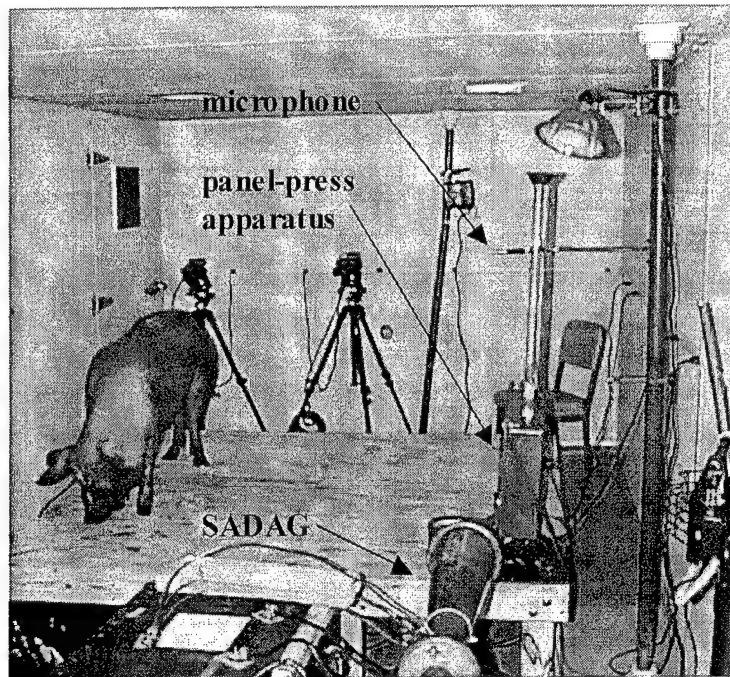


Figure 44. Minipig (subject) on platform with panel-press apparatus prior to exposure with Sequential Arc Discharge Acoustic Generator (SADAG).

### *Procedure and Data Analysis*

*Pre-Exposure Panel-Press Training.* Prior to testing with the SADAG, both subjects — 538 and 544 — had received extensive training with the panel-press apparatus. At the conclusion of training, both subjects pressed vigorously at a steady and reliable rate. A final training session was conducted for each subject approximately 24 hr before they were exposed to the SADAG.

*Exposure to SADAG.* Each exposure session began with one of the investigators leading the subject up the ramp to the asset platform. Once on the platform, the ramp was moved away; that is, the only way for the subject to leave the 46-cm-high asset platform during the session was to jump off. (Subjects clearly preferred not to do this; during the entire pre-exposure panel-press training phase, neither of the subjects ever left the platform by jumping off.) Once confined to the platform, each subject was allowed to freely panel press for food. Panel pressing throughout the experimental session was rewarded on a fixed-ratio 5 reinforcement schedule; every third response was rewarded with approximately 20 g of food.

Following an initial period of approximately 60-180 s, each subject was exposed to a series of single SADAG pulses. For all of the exposures, the output amplitude was set at maximum. Timing of the SADAG pulses was determined primarily by subject behavior. That is, an attempt was made to generate SADAG pulses only when the subject was eating from the food cup or was close (within approximately 10-20 cm) to the cup. Sessions could last a maximum of 30 min but the subject could terminate the session prior to this limit if he escaped from the platform by jumping off. Two exposure sessions, separated by approximately 24 hr, were conducted for each

of the subjects. The occurrence and timing of panel-press responses and SADAG pulses were recorded by videotape.

### *Results and Discussion*

*Acoustic Measurements.* Acoustic measurements during each of the exposure sessions were made by ARL technical personnel. Although data for all of the exposures are not available, ARL recording equipment indicated that the SADAG performed as expected. The average sound pressure level at the subject location was determined to be approximately 165 dB. (See also Figure 32, which illustrates a typical single-pulse pressure waveform generated by the SADAG.)

*Panel-Pressing Task.* Figures 45 and 46 illustrate both the timing of the single SADAG pulse and the cumulative number of panel presses for each subject — 544 and 538, respectively — during the first exposure session. Six pulses were delivered to each subject, although precise timing of the pulse differed. For Subject 544, the first five pulses were delivered in a relatively compressed period of time (approximately 10 s) after the subject had been responding at a relatively steady rate for approximately 3 min, 25 s. The impact on the subject's behavior was fairly dramatic and rapid. In the immediate aftermath of each pulse, the subject either displayed a visible startle reaction (flinch), moved away from the immediate vicinity of the food cup, or both. In addition, following the initial five pulses, the subject's operant rate markedly declined: The subject made only one additional panel press for the remaining 491 s of the session. Finally, as contrasted with the time period prior to use of the SADAG, the subject tended to maintain a greater mean distance from the panel-press apparatus (although this trend was not quantified). A final (sixth) pulse was delivered 11 min, 3 s into the session when the subject was close to the food cup. This final pulse produced a startle reaction similar to that which followed the first pulses. Approximately 42 s after delivery of this last SADAG pulse, the subject jumped off the platform, terminating the session.

For Subject 538, delivery of pulses was not quite as massed in time as for 544. The first two pulses, delivered 65 and 71 s into the session, elicited startle responses similar in magnitude to those of Subject 544. Panel pressing resumed, however, 11 s after the second pulse. Two further pulses (at 3 min, 27 s and 3 min, 36 s of the session), each made as the subject's snout was in the food cup, had the effect of causing the subject to retreat away from the panel-press apparatus. Thereafter, the subject's operant rate declined for a period of time (three panel presses in a period of 7 min, 49 s). After the operant rate began to increase, fifth and sixth pulses were delivered to the subject, in each case when the subject's snout was in or near the cup. In each case, the SADAG elicited a startle response and the subject retreated from the panel press device. Shortly after the sixth pulse (51 s), the subject terminated the session by jumping off of the platform.

Both subjects quickly terminated the second exposure session before any pulses could be delivered. 544 departed the asset platform after approximately 25 s; 538 left after approximately 240 s. Neither subject panel-pressed during the relatively short time they were on the platform.

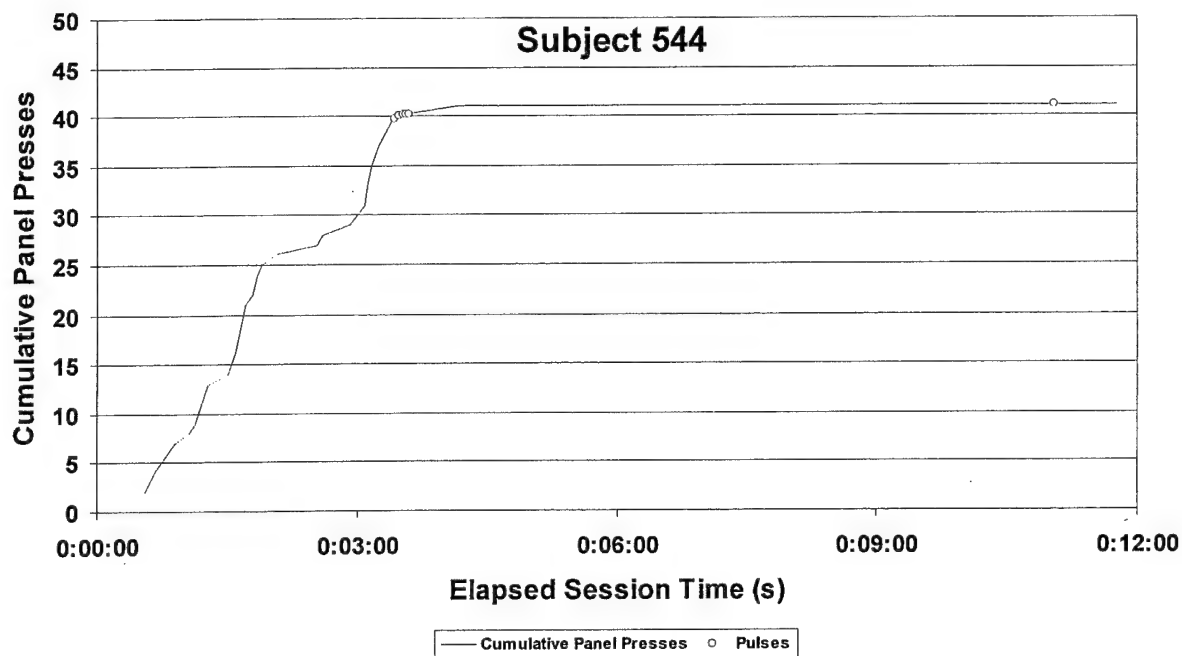


Figure 45. Cumulative panel presses and delivery of single pulses from the Sequential Arc Discharge Generator (SADAG), both as a function of elapsed time, during the first of two sessions for Subject 544.

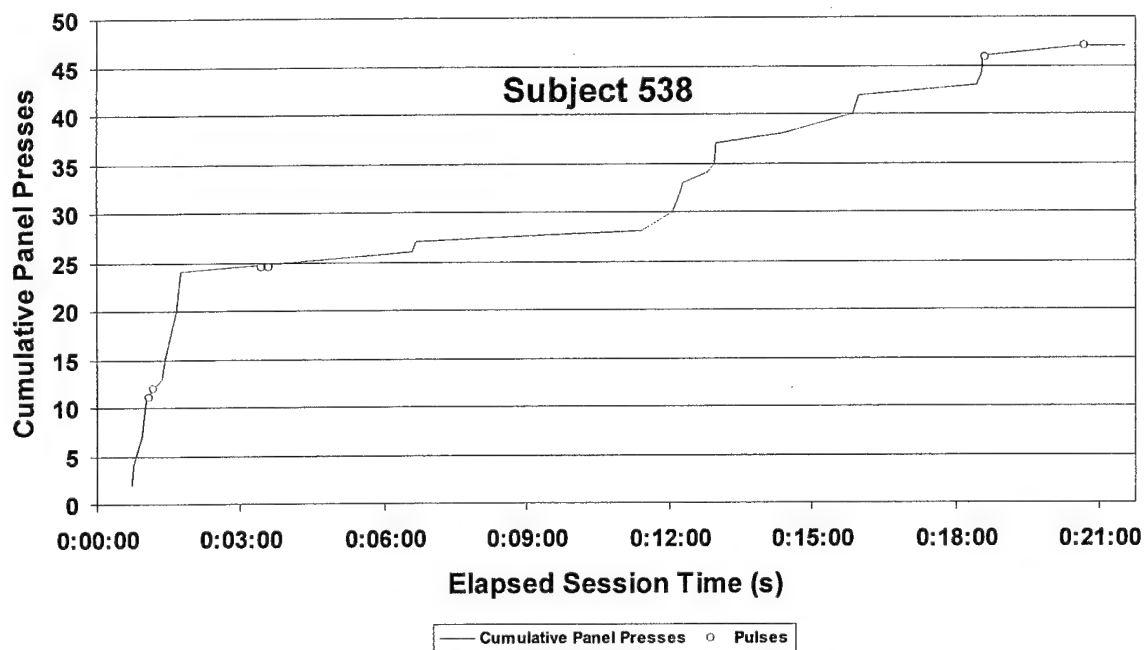


Figure 46. Cumulative panel presses and delivery of single pulses from the Sequential Arc Discharge Generator (SADAG), both as a function of elapsed time, during the first of two sessions for Subject 538.

In summary, the SADAG clearly had a marked impact on the ongoing operant behavior of the subjects in this study. Those effects included a clear startle response that did not appear to diminish greatly, if at all, over the course of the first day of testing; a pronounced decline in the rate of their previously-established operant behavior; and a tendency to avoid the context (the panel press device, specifically, and the platform itself, more generally) associated with the aversive events experienced.

The responses by Subject 538 were somewhat stronger than for 544; that is, his panel-press rate declined more quickly, and his latency to escape the experimental context (i.e., the platform) on both Day 1 and 2 of testing were shorter. This difference may be due to a number of factors: (a) individual differences in reactivity to stressors; (b) the differences in pulse density during Day 1 of testing (i.e., the "massed" presentation of the majority of pulses for 538 versus the more "spaced" presentations for 544); or (c) the difference in the optical barriers employed for the subjects.

If one is to presume that the SADAG output was an aversive stimulus, it remains to be determined precisely what aspect of its presentation was critical in producing the aforementioned outcomes. Although it seems most likely that the effects resulted from the acoustic output of the device and were aurally mediated, other factors may be at work. Although the second optical barrier (used with 544 on Day 1 and thereafter) more completely diminished the light associated with SADAG discharge, it was not *completely* eliminated. Second, as noted earlier, the firing of the SADAG may be accompanied by small amounts of ozone. Whether or not swine can detect this, and — if so — what their reaction to its presence might be, remain unclear.

## GAYL BLASTER

### *Subjects*

Subjects were 5 adult male goats (*Capra hircus*) ranging in weight from approximately 65 to 75 kg. Subjects ranged in age from approximately 8 to 9 years at the time of testing. The subjects were housed and maintained at Brooks Air Force Base, TX, as described in the *General Methods and Procedures* section.

### *Apparatus*

*Acoustic Source.* The Gayl Blaster, designed and constructed by Franz Gayl, was intended to deliver moderate-intensity, relatively complex acoustic energy. The Blaster consisted of a 112.0-cm-long, 20.0-cm-diameter tube which was sealed at one end. Along the center axis of the tube's interior were 33 piezoelectric transducers arranged in 11 layers, each layer consisting of 3 transducers. Layers were separated from one another by a distance that was a fraction of the wavelength at which the transducers worked. Before final assembly, the acoustic performance of the system was predictively analyzed in various configurations with the ANSYS finite element-engineering program (ANSYS Inc., Canonsburg, PA). Figure 47 shows the Blaster.

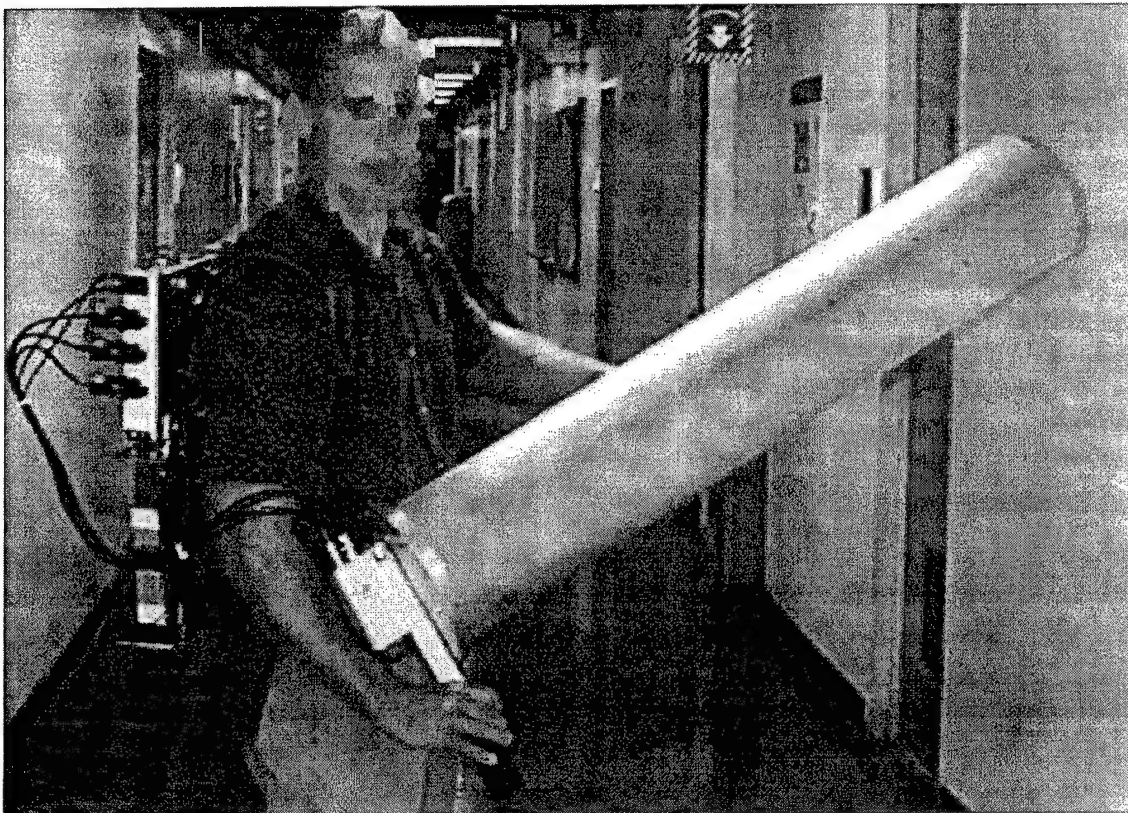


Figure 47. The Gayl Blaster in its hand-held configuration.

A signal generator constructed specifically for the Gayl Blaster controlled the amplitude and frequency of the Blaster's output. The signal generator consisted, in part, of two oscillators, A and B. Oscillator A sent two signals to the Blaster, designated A and A'. (Signal A' was putatively a phase-shifted function of A.) Oscillator B produced one signal, designated B. Eleven piezoelectric transducers, one from each layer, were wired in series and connected to one of the three output signals of the signal generator. The signal generator allowed for independent control of the frequency and phase of the two oscillators. The signal generator also allowed modification of the Blaster's amplitude, but did not allow the amplitude of the two oscillator outputs to be modified independently of one another.

*Panel-Pressing Equipment.* A panel-press device, designed by Whitmore Enterprises (San Antonio, TX) for use by goats and described in detail in the *General Methods and Procedures* section, was employed. Delivery of the food and recording of the panel-press responses were further controlled by various Coulbourn modules (Coulbourn Instruments, Allentown, PA), also described in detail in the *General Methods and Procedures* section.

*Test Enclosure.* Exposures took place inside of a 6.0 m long x 3.7 m wide rectangular test enclosure. The four sides of the enclosure were constructed from 1.1-m-high chain link fence. The test enclosure adjoined the 14.8 m long x 12.3 m wide pen in which the subjects were housed when not being tested. A gate at one end of the test enclosure allowed subjects to move



[illegible]

58

*Acoustic Measurements.* The acoustic output generated by the Gayl Blaster was acquired and analyzed using the Brüel & Kjær hardware (microphones, etc.) and the in-house LabVIEW program described in detail in the *General Methods and Procedures* section. In addition, each of the three individual signals produced by the Gayl signal generator (A, A', and B) was digitally acquired using WINDAQ data acquisition software in conjunction with an analog and digital input/output board (Dataq Instruments, Inc., Akron, OH).

### *Procedure and Data Analysis*

*Pre-Exposure Panel-Press Training.* It was hypothesized that the Gayl device might impact subject behavior differentially based on a number of behavioral dimensions: One of these dimensions was experience with the panel-press apparatus. For example, one might assume that any effects of the Gayl would be more pronounced in the case of untrained subjects (who might have less motivation to access food from the apparatus). Prior to testing with the Gayl Blaster, 4 of the 5 subjects — AL, FL, HG, and HH — had received extensive training with the panel-press apparatus. At the conclusion of training, these 4 subjects pressed at a steady and reliable rate. A fifth subject, HE, had received no prior panel-press training.

A second behavioral dimension considered in the present study was social rank. Goats, like other social animals, tend to form a social hierarchy when housed together (Barroso et al., 2000). One of the ways in which social rank manifests itself is preferential access to food. That is, in any situation in which limited resources are available (as in the panel-press situation with more than one subject present), higher-ranking individuals tended over time to displace lower-ranked ones. It was hypothesized that any effects of the Gayl Blaster would be more evident in lower-ranking individuals than in higher-ranking ones. The 5 subjects in the present study varied in social rank as follows: AL > HG > HH > HE > FL (AL being the highest-ranking goat and FL the lowest). (HG and HH were approximately equal in rank, but — given sufficient time — HG generally displaced HH at the panel-press apparatus.)

*Exposure to Gayl Blaster.* The 5 subjects were tested during three daily sessions. The three daily sessions were separated by 5 to 7 days. Sessions ranged in duration from approximately 19 to 47 min. Each session consisted of either six or five subject exposures (six for Session 1; five for Sessions 2 and 3); exposure durations ranged from 12 to 281 s ( $M = 79.3$  s). The amplitude of the Gayl Blaster was at its maximum setting for all exposures. (In one instance the amplitude of the Blaster was modified during the course of an exposure by rapidly turning the device off and on several times; see Table 4.) For all exposures, the signal generator phase setting for all three of the output signals (A, A', and B) was 0°. Frequency of the Blaster was varied from exposure to exposure and sometimes within an exposure. (Table 4 summarizes these frequency settings.)

Several “scenarios” were examined during the course of testing. These scenarios can be described as follows:

1. Drive away: One or more subjects were already present at the panel-press apparatus as the Gayl Blaster was activated. The gate to the housing area was left open, allowing

subjects to depart from the immediate vicinity of the panel-press apparatus and Blaster.

2. Keep away: The Gayl Blaster was activated and one or more subjects were released from the housing area to the test enclosure through the open gate. (Release of the subject or subjects could immediately follow onset of the Gayl device or could follow it by a short period of time.)
3. Thwarted drive away: One or more subjects were present at the panel-press apparatus as the Gayl Blaster was activated. The gate to the housing area was closed, preventing subjects from departing the test enclosure.

Table 4 summarizes the scenarios examined during each of the 16 exposures. For all exposures conducted during the first session, the Gayl Blaster was in a fixed location, mounted on the wood platform located outside of the test enclosure (see Figure 48). For all subsequent exposures the Gayl Blaster was employed in its hand-held configuration (see Figure 47). During these latter exposures the operator of the Blaster was in the same approximate location as the wood platform. During the course of an exposure the operator would continuously “sweep” the Gayl tube from left to right and back again in a more-or-less regular rhythm, thus aiming the device at multiple points within the test pen. Subject location and behavior (including panel-press responding) during and between exposures was recorded on videotape.

The output of the Gayl Blaster was measured via microphone at several points within the test enclosure immediately prior to each of the daily sessions. As with the subject exposures, during the “measurement” sessions, the amplitude of the Gayl Blaster was always at its maximum setting; similarly, the signal generator phase setting for all three of the output signals (A, A', and B) was always 0°. The output of the Gayl signal generator was captured via WINDAQ data acquisition software each time the device was used — both measurement runs and subject exposures.

Table 4. Experimental conditions for the 5 subjects exposed to the Gayl Blaster.

Session Number	Exposure Number	Exposure duration (s)	Exposure frequency (kHz)	IDs of subjects in test	Scenario tested
1	1	49	3.4	HH, HG, FL, HE	drive away
	2	45	3.4	HH, HG, FL, HE	drive away
	3	45	3.4	HH, HG, FL, HE	drive away
	4	67	3.4	HH, HG, FL, HE, AL (AL released 30 s after exposure onset)	drive away, keep away (in case of AL)
	5	35	3.4	FL	thwarted drive away
	6	28	3.4	FL	thwarted drive away

2	1	78	3.4	HH, HG, FL, HE	drive away
	2	12	3.4	HH, HG, FL, HE	drive away
	3	37	3.4	HH, HG, FL, HE	thwarted drive away
	4	46	3.4	HH, HG, FL, HE	drive away
	5	183	3.4 at outset; increased to 5; increased again to 7	HH, HG, FL, HE, AL (AL released 16 s after exposure onset)	drive away, keep away (in case of AL)
3	1	168	3.4	HH, HG, FL, HE, AL (HH, HG, FL and HE released 9 s after exposure onset; AL released 88 s after exposure onset)	keep away
	2	29	3.4	FL	thwarted drive away
	3	281	3.4 at outset; then varied rapidly from approximately 1-7; also rapidly turned device off and on	HG, HH (both subjects released at moment of exposure onset)	keep away
	4	79	3.4	HE, HH, HG, FL, AL (HE released 15 s after exposure onset; HH, HG, and FL released 22 s after exposure onset; AL released 62 s after exposure onset)	keep away
	5	87	3.4 at outset; then varied rapidly from approximately 1-7	FL	thwarted drive away

## Results and Discussion

*Acoustic Measurements.* Figure 49 illustrates the output of each channel of the Gayl signal generator during a representative exposure during the first of three test days. Note the difference in both amplitude and waveform between A and A', on the one hand, and B, on the other. Between the first and second test sessions, two alterations were made that had a potential effect on operation and output of the Blaster. First, a replacement signal generator was constructed and employed. The second generator putatively provided more precise control over the frequency setting for the three signals. Second, each of the 33 piezoelectric transducers inside of the Blaster tube was examined; five defective transducers were isolated and the Blaster was re-wired so that these defective transducers were bypassed. Figure 50 shows the output of each signal following these changes. The discrepancy involving Signal B is largely absent. However, these alterations, while they impacted the wave-shape of the signals, did not significantly affect the output amplitude of the Blaster.

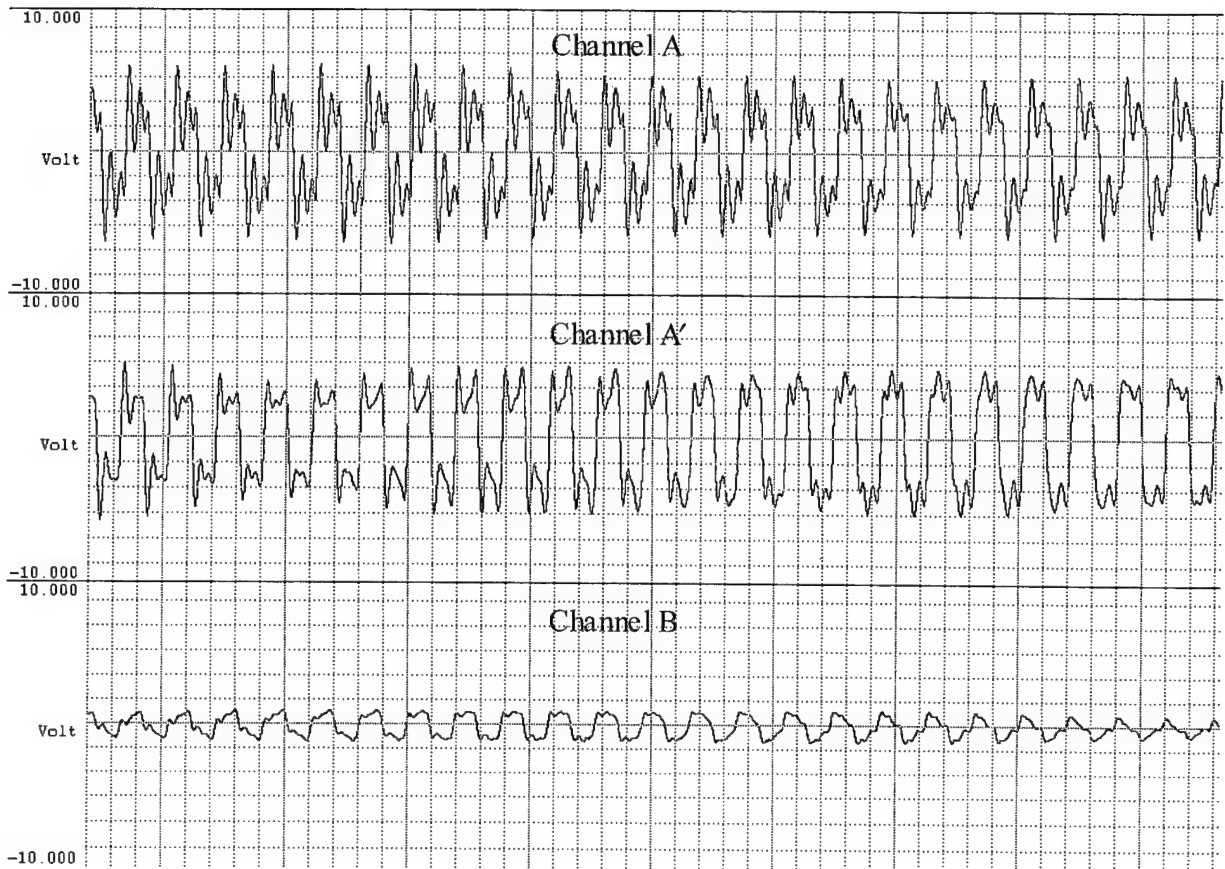


Figure 49. Output of the three channels of the Gayl signal generator prior to repair work on the Gayl transducers and replacement of the signal generator. (Grid lines along the x-axis are increments of 0.16 ms.)

The amplitude and frequency content of the Gayl Blaster was measured prior to each of the three exposure sessions. The majority of the measurements were acquired with the Blaster frequency set at approximately 3.4 kHz (the setting employed for the majority of the exposures). The amplitude of Gayl device varied somewhat from measurement to measurement, but not in any predictable manner over the course of the three test sessions. In contrast, the frequency content of the individual measurements did vary substantially from test session to test session. For example, during the second test session, the mean fundamental for all of the measurements taken at the 3.4 kHz setting was 3226.11 Hz ( $SD = 12.89$ ); the mean fundamental for all of the 3.4-kHz measurements acquired during Session 3 was 3382.36 Hz ( $SD = 10.40$ ). This inter-session difference was, however, not a consequence of differences in the operating characteristics of the Gayl Blaster, but rather due to the difficulty of precisely setting the frequency of the device using its associated signal generator. Table 5 summarizes the mean amplitude of the Gayl output (at the 3.4 kHz setting) for a number of points inside of the test pen. The measurement points (a-f) refer to locations shown in the schematic of the test pen (see Figure 48). For all of the summarized measurements, the Blaster's location was fixed (not swept) and it was aimed at Point a.

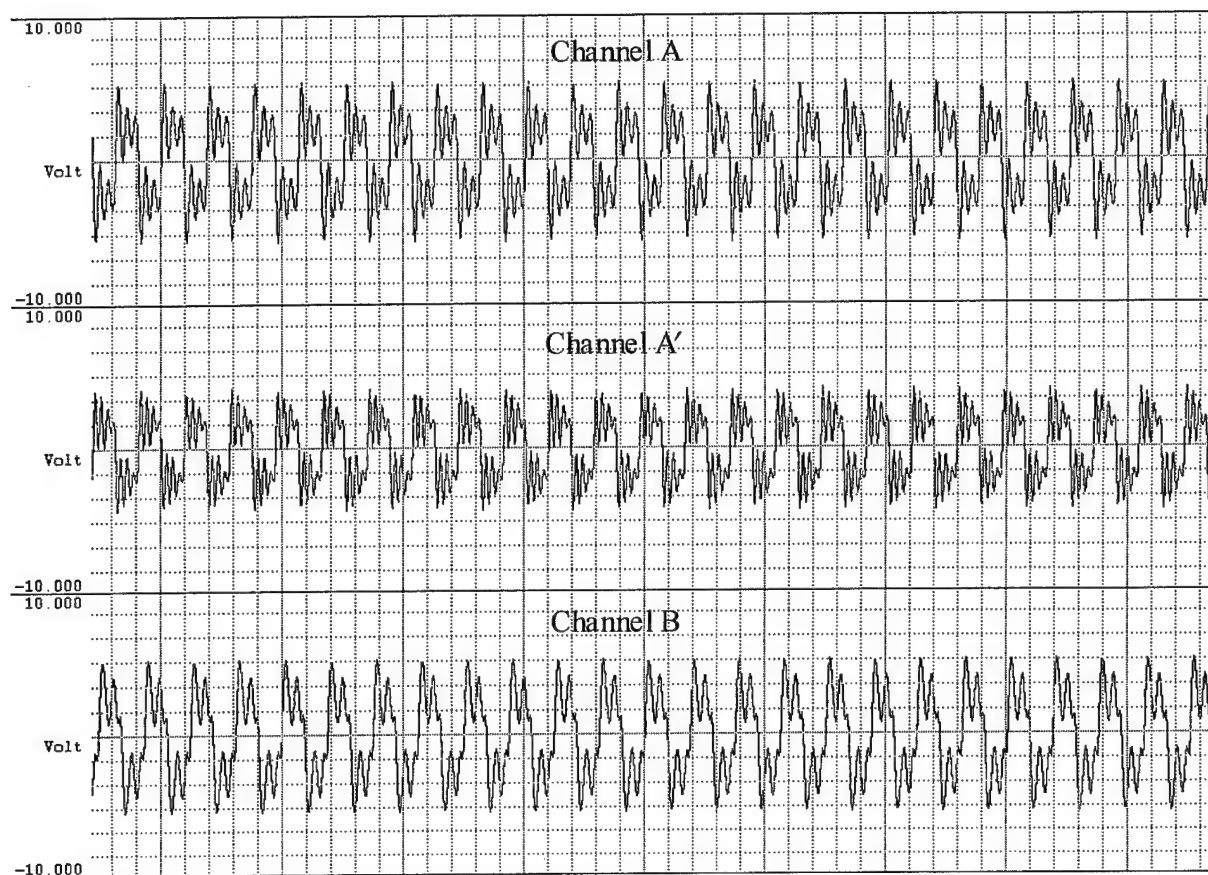


Figure 50. Output of the three channels of the Gayl signal generator following repair work on the Gayl transducers and replacement of the signal generator. (Grid lines along the x-axis are increments of 0.16 ms.)

Table 5. Mean amplitude of Gayl Blaster (when fundamental frequency set at 3.4 kHz and amplitude at maximum) for different points within the test enclosure.

Measurement point	Distance from Gayl Blaster (cm)	Mean amplitude (dB) at fundamental frequency
e	45.0	126.18
d	130.0	112.92
a	240.0	107.06
b	258.9	103.30
c	325.6	85.65
f	630.8	90.61

*Subject Behavior.* In overview, to the extent that the Gayl Blaster had any impact on subject behavior, it was extremely minimal. Examination of the videotapes showed that the onset of the device would very occasionally elicit a brief orienting response. The occurrence of such



responses diminished rapidly over the course of the three test sessions. The Gayl Blaster never elicited from any subject a response that visually resembled a startle response. Furthermore, the only variable that seemed to affect subject operant behavior (panel pressing) or location with the test and housing enclosures was social rank.

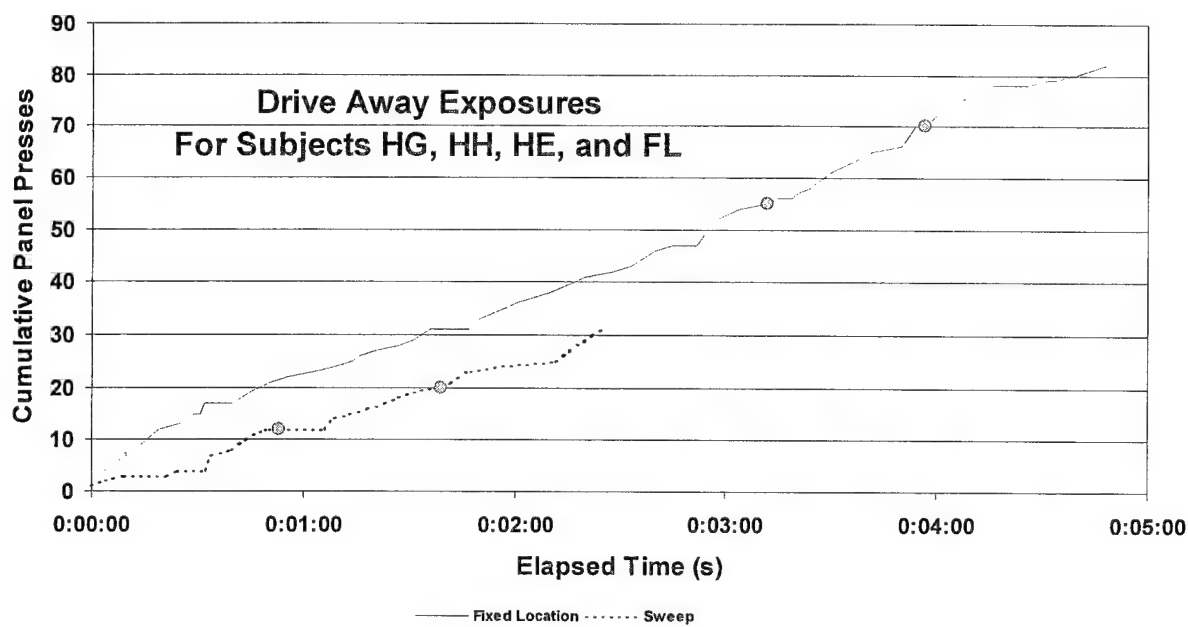


Figure 51. Cumulative panel presses for 4 subjects and onset/offset times of the Gayl Blaster for two drive away exposures. (Filled circles represent the onset and offset times of the Blaster for each exposure.)

Figures 51-53 show representative subject panel-pressing behavior under a number of conditions during 6 of the 16 exposures. Figure 51 depicts the operant behavior of Subjects HG, HH, HE, and FL during two separate drive-away exposures. In the case of one exposure the location of the Blaster remained fixed (Session 1, Exposure 3); in contrast, the position of the Blaster was varied throughout the other exposure as the operator swept the device from side to side (Session 2, Exposure 4). Frequency was set at 3.4 kHz for both exposures. The figure shows that panel-press rates remain relatively constant throughout the entire period examined — before, during, and after exposure; more specifically, onset of the Blaster does not cause a drop in the operant rate. (There is a brief drop in rate of responding for Session 2, Exposure 4 that precedes and overlaps onset of the Gayl Blaster. This cessation in responding was a result of aggressive interaction between Subjects HG and HH at the site of the panel-press apparatus as they competed for access to the grain. In fact, panel pressing *resumed* shortly after onset of the Gayl Blaster.)

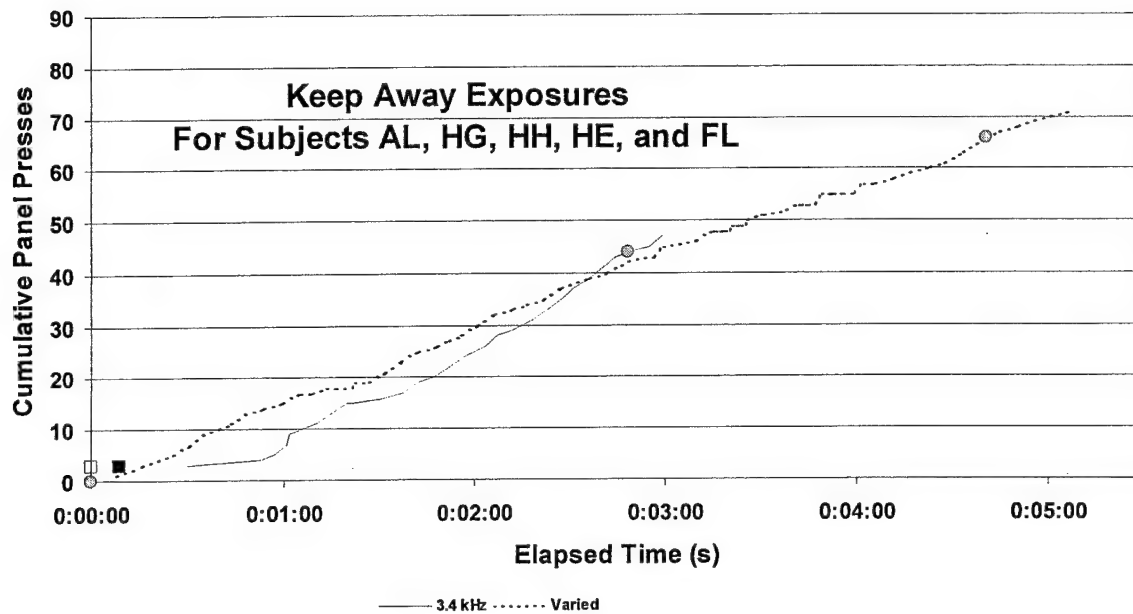


Figure 52. Cumulative panel presses for 5 subjects, subject release times, and onset/offset times of the Gayl Blaster for two keep away exposures. (Filled circles represent the onset and offset times of the Blaster for each exposure. [Onset time for each exposure is 0:00:00.] The open square represents the initial release time for the varied-frequency exposure; the filled square for the 3.4-kHz exposure.)

Figure 52 illustrates the panel-pressing behavior of AL, HG, HH, HE, FL during two keep-away exposures. The position of the Blaster was varied by sweeping for each exposure. In the case of one of the exposures (Session 3, Exposure 1, involving Subjects AL, HG, HH, HE, FL), the frequency of the Gayl Blaster was fixed at 3.4 kHz. In the case of the other exposure, (Session 3, Exposure 3, involving Subjects HG and HH), frequency was varied during a great portion of the exposure. Frequency for both oscillators was set at 3.4 kHz at the outset of the exposure, but was subsequently modified by rapidly modulating the frequency control for Oscillator B (but not A) over its entire range (see also Table 4). In the case of both exposures, subjects tended to enter the test pen almost immediately following the opportunity to do so. (For Session 3, Exposure 1, Subject HE entered the test enclosure at almost the exact moment the gate was opened; Subjects HG and HH entered 4 s later; Subject FL remained in the housing pen, but this tendency of FL — the lowest-ranking goat — to remain in the housing pen was also evident during those portions of testing when the Gayl Blaster was *not* on. AL was given the opportunity to move through the gate into the test enclosure 73 s after the gate was first opened and did so almost immediately. Similarly, for Session 3, Exposure 3, both of the subjects' tests — HG and HH — entered the test enclosure almost immediately after the connecting gate was opened.) Not only did operation of the Gayl fail to deter subjects from entering the test pen, it also failed to keep them from the panel-press apparatus. (For Session 3, Exposure 1, Subject HE was at the site of the panel-press equipment within 4 s of entering the test enclosure; HH and HG were at the site of the panel-press equipment within 2 s of entering the enclosure; and AL was panel pressing 9 s after entering the test pen. For Session 3, Exposure 3, both HH and HG were adjacent to the panel-press apparatus 3 s after they entered the test pen.) Once at the site of the

panel-press apparatus, panel-pressing commenced and continued at a relatively steady rate throughout the entirety of the exposure. The relatively short latency between entry into the enclosure and panel-press activity was due to (a) consumption of any grain already in the food cup, and (b) aggressive competition for access to both the grain and the manipulandum. Because the presence of a greater number of individuals tended to positively correlate with the amount of aggressive behavior/competition, this also accounts for the relatively slower operant rate evident at the outset of Session 3, Exposure 1 (where 3, as opposed to 2, subjects were initially present at the panel-press device).

Finally, Figure 53 depicts two separate thwarted drive away sessions that utilized the lowest-ranking subject, FL. During testing, when other subjects were present inside of the test enclosure, FL never panel-pressed, and was frequently situated either in the back of the enclosure near the entrance gate or in the adjacent housing area. However, when isolated from the other subjects, as in these two exposures, FL panel-pressed at a reliably constant rate that did not seem affected in any fashion by the acoustic output of the Blaster.

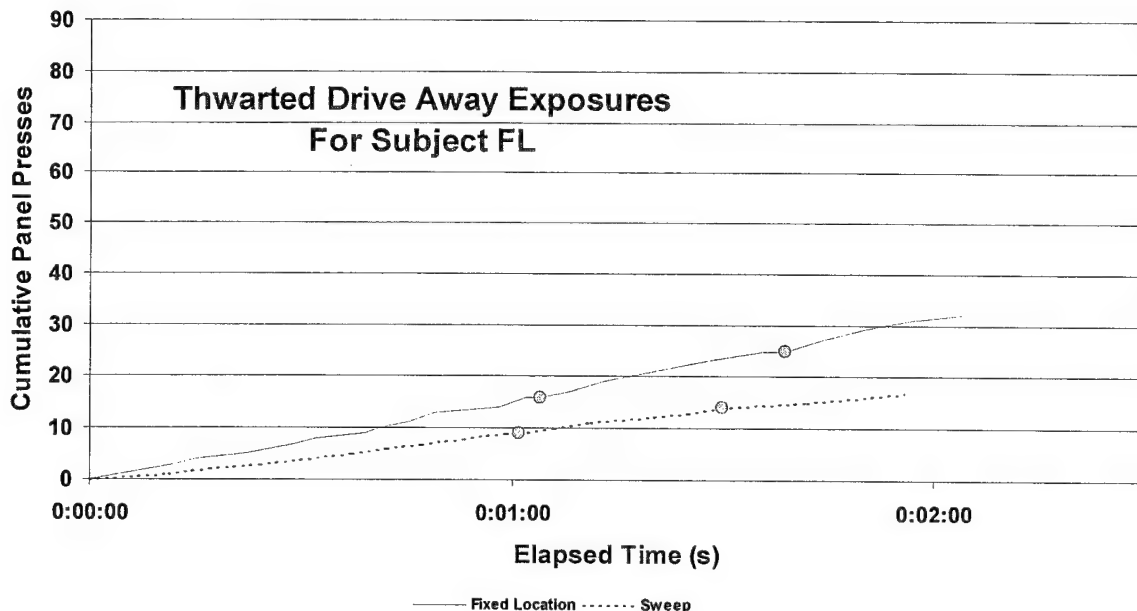


Figure 53. Cumulative panel presses for Subject FL and onset/offset times of the Gayl Blaster for two thwarted drive away exposures. (Filled circles represent the onset and offset times of the Blaster for each exposure.)

In summary, the output of the Gayl Blaster failed to alter the behavior of goats engaged in goal-directed behavior in any measurable fashion. It failed to produce any visible startle responses; it failed to drive subjects engaged in panel pressing away and failed to affect their operant rates; it similarly failed to keep away subjects from the panel-press site and — once they arrived at the site — to begin panel pressing. Furthermore, the Blaster had no differential impact on subject behavior that was a function of social rank. Given sufficient opportunity both the highest- and lowest-ranking subjects (AL and FL, respectively) engaged in panel pressing. In addition, the Blaster had no differential impact on subject behavior based on prior training;

specifically, it was suspected that Subject HE — with no prior panel-press training, might be less well motivated than his cohorts to remain at or the enter a site in which a potentially acoustic aversive stimulus was operating. However, Subject HE's location and behavior did not appear to be affected in any way by the Blaster's output (as demonstrated in part by his rapid entry into the test site during Session 3, Exposure 1). Finally, modifying the operating parameters for the Gayl device did not appear to alter its effect on subject behavior. Neither increasing nor modulating the frequency content of the signal altered its impact; nor did sweeping the device in its hand-held configuration.

## GENERAL DISCUSSION AND CONCLUSIONS

The compressed-air-driven siren (CADS) significantly impacted performance on the Primate Equilibrium Platform (PEP) of some rhesus monkeys during some exposures. However, rather than being mediated by the acoustic properties of the siren signal per se, the effect was probably due to the substantial air flow created by the siren, pushing against the front of the PEP chair, and thereby preventing optimal operation.

The effects of the combustion-driven Dismounted Battlefield Battle Laboratory (DBBL) siren on the goal-directed behavior (panel pressing for food) of goats were both minimal and transient. The siren onset often produced startle and/or orienting responses that persisted for some seconds, but this may have been due to the initial popping noise as opposed to the lower-amplitude, sustained signal that followed. In addition, the siren had only a minimal impact on panel-pressing rates.

Exposure to the impulsive acoustic device, the Sequential Arc Discharge Acoustic Generator (SADAG), produced long-term hearing deficits in rhesus monkeys exposed to its signal for a period of time as brief as 30 s, but had only minimal impact on PEP performance. In contrast, the SADAG, however, clearly had a marked impact on the ongoing operant behavior of swine engaged in a panel-pressing task. Although the effect could have been aurally mediated by the acoustic output of the device, other factors such as light and ozone associated with SADAG discharge could have been involved.

The Gayl Blaster had no significant effects on the goal-directed behavior of goats. Its onset produced an occasional orienting response, but no detectable startle responses. It failed to impact either the location or operant rates (panel-pressing for food) of the subjects.

On the basis of our experimental results, it appears to be unlikely that acoustic energy in the audible frequency range up to approximately 165 dB in intensity will provide useful "extra-aural" effects. Thus, it appears that narrow-band, high-intensity acoustic energy in the audible frequency range would not have much utility as a non-lethal weapon. One device (the SADAG) disrupted the goal-directed behavior of one species (the pig). However, this same device had very little effect on the behavior of another species (the rhesus monkey), while at the same time inducing significant and long-term hearing threshold shifts. (Hearing damage could have occurred in the pigs as well as the monkeys, but due to limitations of the equipment, auditory thresholds could only be assessed in the latter species). Hearing damage alone is probably

sufficient cause to exclude the use of a device as a non-lethal weapon. In summary, none of the four devices tested would have obvious utility as a non-lethal weapon.

These experimental results support the suggestion of other reviewers (e.g., Alker, 1996; Altmann, 1999) that development of a useful weapon using high-intensity acoustic energy is extremely unlikely. A review of the blast overpressure literature and theoretical analyses strongly indicate that considerable energy would be required to induce even threshold “extra-aural” effects. The size and power requirements of such a system are serious obstacles to the development of a useful weapon. As noted by Alker (1996), simply on the basis of laws of physics, the inability to produce high levels of acoustic energy at useful ranges seems to be insurmountable. The lack of useful bio-effects at realistically achievable sound pressure levels, as demonstrated in the present study, reinforces the notion of limited usefulness of high-intensity acoustic energy in the audible frequency range as a non-lethal weapon.

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